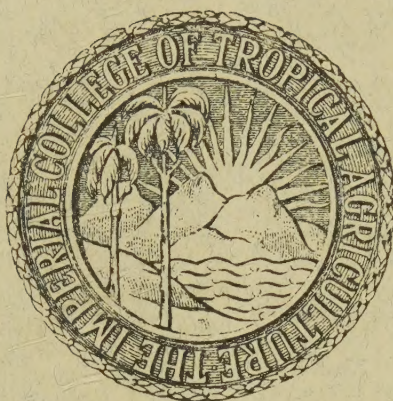


THIRD ANNUAL REPORT ON CACAO RESEARCH 1933



Via colendi haud facilis.

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1933



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PLATE I



FIG. 1. Pod of Imperial College Selection 1. (Natural Size)



FIG. 2. Pod of Imperial College Selection 2. (Natural Size)

PLATE III

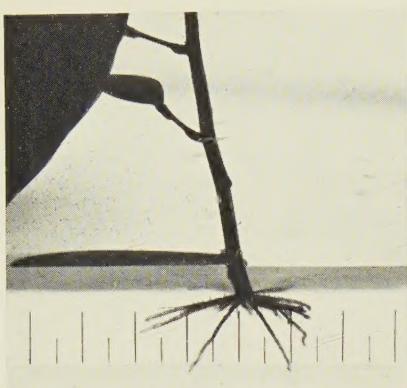


FIG. 1

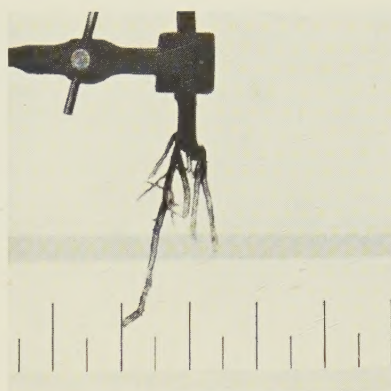


FIG. 2



FIG. 3

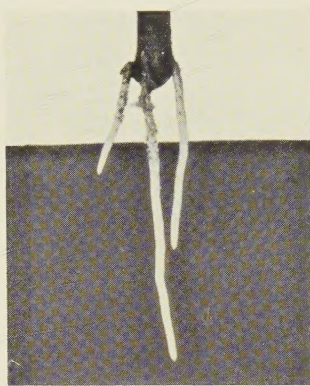


FIG. 4

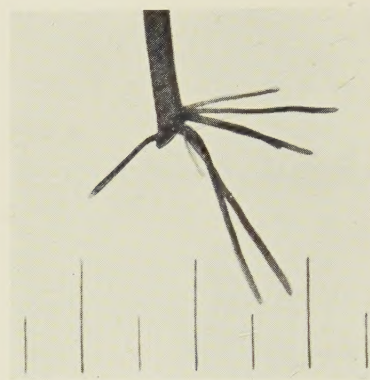


FIG. 5



FIG. 6



FIG. 7

TYPICAL ROOT SYSTEMS OF CACAO SOFTWOOD CUTTINGS

FIGS. 1 and 2. Forastero, fan and chupon respectively.

FIG. 4. Surinam Wild Cacao, chupon.

FIG. 5. *Th. pentagona*, fan.

FIG. 3. Criollo, chupon.

FIG. 6. *Th. angustifolia*, fan.

FIG. 7. Plant raised from a chupon cutting. Age, 11 months. Height, 1 metre.

THIRD ANNUAL REPORT ON CACAO RESEARCH, 1933.

A.—BOTANICAL SECTION.

THE BOTANICAL PROGRAMME OF 1933.

By E. E. CHEESMAN, M.Sc.

WORK during 1933 has been very similar to that of previous years, with the difference that routine consolidation of the progress already reported has assumed greater prominence than new researches.

Propagation Studies.

As foreshadowed in the Second Annual Report, propagation of selected trees has demanded the chief attention. 1933 has not been a fortunate year for vegetative propagation of cacao, the excessively wet weather reacting most adversely on the quality of cutting material available on the selected parent trees. Nevertheless we now have some 250 plants of 60 clones established for further multiplication.

In addition to routine propagation Mr. Pyke has been able to extend his comparisons of different types of cuttings and of cuttings from various kinds of cacao and he has also, as anticipated last year, obtained some information concerning the differentiation of "fan" and "chupon" buds. The object of the latter investigation was to find some means of converting "fan" material into "chupon" material in the nursery in cases where few or no chupons occur on the parent tree. Whilst it cannot yet be claimed that this change can be accomplished quite at will, a degree of success was obtained which should be sufficient for practical purposes. This closes a gap in the nursery technique, and enables us to propagate from any available material and subsequently convert it into the type of branch or bud required.

Propagation in 1934 will be almost entirely routine, as we now have to bulk up sufficient material for field comparisons of both stocks and scions. A provisional draft programme provides for propagation of some 2,000 cuttings and 2,000 buddings in the early months of 1935, and the necessary shoots and buds, some of fan and some of chupon type, must be grown in the nursery during the intervening period.

Genetic Survey.

Genetic survey was virtually completed in 1932, and has given place to a practical selection programme, but two pieces of work done this year may fittingly be mentioned under this heading.

Earlier work had shown that correlations between the external characters constituting "type" and the more important quantitative characters are too slight to be utilised in practical selection for yield. Mr. Pound has now shown by a preliminary survey of pigments that external characters are similarly almost useless as indicators of bean colour, which is one of the component factors in quality. His study is styled preliminary because it is necessarily an incomplete investigation of highly complex inheritance, but for our present practical purposes it goes almost far enough and there is no intention to pursue it to a complete analysis of the inheritance of pigmentation at the present stage of research.

An analysis of variability in budded cacao, carried out on what is probably the only material anywhere available for the purpose, has given results in accordance with expectation. Budded progeny are markedly less variable than seedling progeny of the same trees, but at the same time there are definite indications of variation induced by seedling rootstocks, not only in yield but also in size of bean. The next stage here must be direct comparison between seedling and clonal stocks, which cannot be made for several years.

Selection Programme.

The full selection programme was drawn up in 1932 to proceed in three stages, viz. (1) Preliminary location of 1,000 trees passing certain standards of pod size and bean size. (2) Reduction of the 1,000 to 100 on the basis of total yield, allowance being made for the size of the individual trees. (3) Reduction of the 100 to whatever smaller number may ultimately prove desirable, on the basis of detailed field comparison of progenies—gross yield, quality of product and agricultural behaviour being all taken into account.

In practice it has proved possible and advisable to start on the second stage before completing the first. Some 750 of the 1,000 trees required in the first stage have been found, and the number is steadily growing, but rather more than half of those first tagged have been discarded again on the yield test, and detailed records are being kept of 350. Thirty-six trees have either had their yields recorded for some years by the Trinidad Department of Agriculture or have given such outstanding

yields in two years of observation that they can be judged now, and these have been given I.C.S. (Imperial College Selection) numbers and are ready for stage 3. These are therefore being propagated for the field test of progenies, and since no direct comparison can embrace 100 types at one time we shall not wait for completion of stage 2 before beginning stage 3.

Nine vigorous and heavily bearing trees have been selected as promising parents for clonal rootstocks, on the assumption that they have themselves vigorous root-systems which may be transmitted to vegetative offspring.

Mr. Pound presents descriptions of the first I.C.S. types, which will be continued until the hundred is made up, and the principles underlying the selection programme are treated more fully in the text.

Studies of Fruitfulness.

Researches in general physiology have during 1933 received less attention than formerly, owing to concentration on selection and propagation. They have, however, included detailed field observations by Mr. Pyke on a number of trees forming the material of a fertilizer experiment laid down by the Trinidad Department of Agriculture. These observations must be continued for another year before any conclusions can be drawn, but it is hoped that our studies of fruit setting and shrivelling will be advanced by the information thus acquired. The experiment itself is described in this Report by Mr. Pound in collaboration with Mr. J. de Verteuil of the Trinidad Department. It provides an illustration of the use of uniformity data in field experiments with cacao, and thus follows logically on our treatment of this subject mentioned last year.

Student Investigations.

During the Session 1932-33 three post-graduate students of the Imperial College of Tropical Agriculture were engaged on minor problems arising out of the programme of the Cacao Research Scheme.

Messrs. W. E. Freeman and H. C. Thorpe examined the relationship which might exist between the presence of pigment in the beans and its occurrence in various other organs of the plant. The aim was the same as that of Mr. Pound's parallel study of pigment factors, namely to provide a means of correlating one of the undoubted quality factors (degree of pigmentation of "nibs") with some external features of the plant. The work involved a standardisation of the degrees of pigmentation in the various parts, classification by the pre-determined standards of a large number of trees, and analysis of the correlations exhibited.

Mr. J. Marshall studied the possibilities of fluctuation in the degree of pollen incompatibility exhibited by certain trees from time to time. His aim was to amplify the data on self-incompatibility already presented by Pound, with special reference to the question whether one and the same tree may be self-incompatible at one season yet self-compatible at another. The work involved hand pollinations of as many flowers as possible on certain trees over the period from October to May.

The results of these researches are incorporated in manuscript dissertations now filed in the I.C.T.A. Library, and as the papers are unlikely to be published *in extenso*, abstracts are here presented to complete the record of the year's work. The abstracts have been prepared by Mr. F. J. Pound.

Other Work.

It is worthy of record in conclusion that Mr. Pound took the opportunity afforded by a vacation in England to discuss quality in cacao and buyers' requirements with a number of leading brokers and manufacturers. The information gained should be of the greatest importance in guiding the selection programme, since although yield is the first desideratum there are other aspects of tree efficiency which cannot be ignored. Our thanks are due to all who contributed information and criticisms of our standards, and we hope that our contacts with both sides of the cacao industry, the growers and the users, will be maintained and increased.

THE VEGETATIVE PROPAGATION OF CACAO.

III.—Observations on Varietal Differences in the Rooting Behaviour of Cacao Cuttings.

By E. E. PYKE.

In the course of propagation studies with different types of cacao, variations were observed in the time required for rooting, and in the habits of the root-systems formed. There was, for example, generally a marked difference in Forastero types between the root systems of fan and chupon cuttings (*Second Report*, p. 4 and text figure 1.) which was also found to hold good when the cuttings were taken from the same tree. In other varieties also, there was evidence that the root systems from uniform cuttings tended to be specific for a given variety and type of cutting.

Material.

In addition to a considerable number of types of plantation cacao (Forastero variety), the varieties known as Trinidad Criollo,* "Alligator" (*Th. pentagona* Bern.) and Surinam wild cacao (possibly *Th. leiocarpa* Bern.) were used. Experiments were also made with two species of *Theobroma* which are not regarded as sources of commercial cocoa, *Th. bicolor* H.B.K. ("Tiger

* A white-beaned variety found very occasionally in Trinidad, and believed to be the descendant of the original Criollo type planted previously to 1727.

Cocoa"), and *Th. angustifolia* D.C. The greatest amount of data has been collected from the Forastero cacao, as several selected strains have been worked with. In view of the mixed genetic constitution of this variety in Trinidad, a certain amount of inherent variability in rooting capacity might be expected. Some indications of this were noticed, but as rooting depended so largely on the vegetative condition, *i.e.*, vigour and maturity of the cuttings, it was found impossible to ascribe significance to inherent factors with the small amounts of uniform material available. However, no strains of Forastero cacao have so far been found which were impossible, or even very difficult to root.

Method.

Semi-hardwood material of either fans or chupons was carefully selected for suitability in making cuttings, which were rooted in a concrete cool frame, using a technique described in a previous paper (*Second Report*, pp. 3-9.). Most of the trials were made in a medium grained calcareous sand from the sea shore, but other grades of sand were used for some batches. The species *Th. angustifolia* was found to be very intolerant of calcareous sand, but was successfully rooted in a bed prepared from well rotted mould from decayed trees. In lifting rooted cuttings the root systems were sketched and occasionally photographed, before repotting for hardening off. In some comparative trials the number of roots and the approximate total length of roots were noted, also the number of leaves retained on the cutting at the time of lifting.

Observations.

Forastero Cacao. The most noticeable feature of the rooting habit of this variety is the dimorphism exhibited between the root systems of fan and chupon cuttings, and already noted (*see also* Plate III, figs. 1 and 2). Further work has shown, however, that while the fans very rarely depart from the characteristic type, *i.e.*, the roots spreading at an angle of between 72° and 60° to the vertical, chupons exhibit a range of root systems, from the vertical "tap root" (text fig. 1) to an almost horizontal type (text fig. 2). In the majority of Forastero chupons however one or more of the roots tend to take up a vertical position, either from the time of emergence, or after making several centimetres of sloping growth. Hence if this habit is maintained after planting out, chupon cuttings should prove comparable to seedlings in depth of rooting. That chupon cuttings are not inferior to seedlings in respect of top growth in the first year was shown by the headway made by cuttings planted out during 1933. The photograph (Plate III, fig. 7) of one of these plants was taken in November, 1933, ten months from the date of setting in the propagator, and eight months after planting out. At the time of planting the cutting had a height of 22 centimetres, within four months the height was 58 centimetres, when a jorquette was formed, and after eight months the plant had a well formed branch system, and was over a metre high.

Trinidad Criollo Cacao.—Seedlings of this variety were obtained from trees growing wild in the Montserrat district of the Central Range of



TEXT FIGURE 1.



TEXT FIGURE 2.

Trinidad. At the time of taking cuttings the seedling trees were between three and four years old, and were growing vigorously in a College nursery plot. Both chupon and fan cuttings rooted readily, at least equally well as Forastero cuttings of similar vigour. Table 1 gives comparative rooting data of the two varieties. The sample of 43 Criollo cuttings represented practically all of this variety propagated during 1933, while the sample of 54 Forastero cuttings was made up of batches, selected at random, propagated at about the same times as the Criollos.

Table 1.

	Criollo.	Forastero.
Number of cuttings set	43	54
Total number rooted ..	31	42
Percentage rooted ..	72%	78%
Mean time of rooting in days ..	$23.0 \pm 7.5\%$	$25.4 \pm 6.5\%$
Difference of means ..	=2.4	
S.E. of difference ..	=2.38	

From the figures it is seen that there was no significant difference in the time required for cuttings to root, and significance could not be ascribed to the small difference in final percentage rooting of the two varieties.

In both cases the mean period for rooting was just over three weeks, but the relatively large coefficients of variability indicated that the cuttings might be divisible into two classes in respect of rapidity of rooting. Grouping the two varieties together and using the grand mean (24 days) as an arbitrary point to separate the classes, there was evidence for two periods of rooting, one with a mean at 18.9 days and the other with a mean at 39 days, about double the time. Table 2 records the data.

Table 2.

Number of cuttings set ..	97
Total number rooted ..	73
Mean time of rooting ..	$24.2 \text{ days} \pm 5.08\%$
Cuttings rooting in under 24 days ..	53
Mean time in days ..	$18.9 \pm 2.01\%$
Cuttings rooting in over 24 days ..	20
Mean time in days ..	$39.0 \pm 4.62\%$

Surinam Wild Cacao.—Cuttings were taken from trees 3 to 4 years old, raised from seeds introduced by Dr. Myers from the Mamaboen Creek district of Surinam. The young trees were grown adjacent to the Trinidad Criollo trees in a nursery plot and were comparable in age and vigour. Softwood chupon cuttings were taken from both varieties and were compared for rooting

in the same propagator. No morphological differences could be detected between cuttings of the two varieties. A distinct difference was apparent however in the rooting behaviour. Table 3 shows that the Surinam cuttings were much slower in initial rooting than the Trinidad Criollos. Also the types of root systems were contrasted. The Surinam cuttings all sent out vertical roots whereas the Criollo cuttings formed more spreading root systems, which could be described as shaped like the ribs of an umbrella. These two types are illustrated in Plate III, figs. 3 and 4.

Table 3.

10 Cuttings of each variety set. Cuttings examined on 25th day.

	Criollo.	Surinam.
Number rooted ..	8	3
Mean number of roots per rooted cutting ..	6.5	3.3
Mean total length per rooted cutting ..	14.25 cms.	5.5 cms.
Direction of growth ..	Almost horizontal curving to vertical	Vertical

It must be noted that the results in Table 3 represent the difference between the two varieties in initial rapidity of rooting. Space was not available to continue the trial any longer, but the unrooted Surinam cuttings were kept under observation in another frame and most of them eventually rooted. That this variety was not inferior in ultimate rooting was also indicated by another trial in which ten cuttings of each of the three varieties, Criollo, Forastero and Surinam were compared. In this case the cuttings were examined for rooting at 17, 24, and 33 days after setting. As shown in Table 4, the Surinam cuttings lagged behind the other in the early stages, but had practically caught up after 33 days.

Table 4.

Variety.	Criollo.			Forastero.			Surinam.		
Days.	17	24	33	17	24	33	17	24	33
Just rooted	4	3	—	3	2	—	1	5	2
Well rooted	3	5	8	1	5	7	—	1	6
Total rooted	7	8	8	4	7	7	1	6	8

Theobroma pentagona Bern. "Alligator cacao".—This species is capable of hybridising with other types of cacao and probably represents a constituent of some Criollo strains. The species has a

characteristic warty pod, pentagonal in section, containing large white beans. In habit it is noticeable for the rarity or absence of true chupons, and consequently of the "jorquette" type of branching. The seedling axis of hybrids, and suckers from it frequently have a 1 : 2 phyllotaxis although of orthotropic growth. Cuttings from a few pure *pentagona* trees were studied for rooting. The trees however were of poor vigour and insufficient material was obtainable for comparative tests with other varieties. Although occasionally vigorous shoots were found, they rooted rather slowly, and were difficult to harden off. It is hoped however that the cuttings propagated, when layered, will yield material more comparable, for propagation work, with the other varieties.

The root systems formed by the *pentagona* cuttings were similar to those of Forastero fan cuttings (Plate III, fig. 5).

Th. angustifolia D.C.—Fan cuttings of this species were rooted in the cool frame. In the calcareous sand used for cacao propagation, no rooting took place, the leaves being rapidly shed. However in a bed prepared from well rotted mould from decayed trees the cuttings remained healthy and began to root at about forty days, nearly all being rooted by 90 days. The youngest shoots, (just matured flushes) rooted most readily. Basal callus was slow to develop in both media. The root system was characteristic, consisting of two, or in some cuttings, three stout main roots forming an angle of 45° to the vertical, and developing lateral roots (Plate III, fig. 6).

Th. bicolor H.B.K.—Several batches of fan cuttings of this species were tried but no rooting occurred. Cuttings usually shed their leaves, but in some cases sent out young leaves subsequently which remained fresh for many weeks in the propagator. The cuttings also callused well.

THE VEGETATIVE PROPAGATION OF CACAO.

IV.—Propagation by Softwood Cuttings under Estate Conditions.

BY E. E. PYKE.

Attempts have been made from time to time at the Imperial College of Tropical Agriculture to propagate cuttings of cacao under field conditions without using elaborate propagating frames. The first attempt was during the rainy season of 1931 when a pit was dug about 6 ft. sq. and 1½ ft. deep and the floor covered with sand to a depth of about six inches.

Fan branch cuttings were set in the sand and were protected from sun and wind solely by shades and windbreaks of palm leaves, no glass being used. The cuttings were set almost horizontally, further to reduce the effects of wind. Although a few cuttings kept moderately fresh for a week or two the majority showed signs of desiccation within a few days, and none of them rooted. It was evident that sealed chambers were necessary in order to maintain a sufficiently high humidity. During 1932 several trials were made with pits covered with glass. Both unmounted panes laid over the earth pits, and glass lighted wooden covers were tried. Some pits were dug on a small plot of young cacao under Saman shade, which during wet weather approached estate conditions of shade, temperature and humidity. Unfortunately the pits were constantly becoming flooded or water logged, which spoilt a good many trials, but sufficient data were obtained to show that under better conditions the pit method should yield results. The pits were made 4 ft. long by 1½ ft. wide by 1½ ft. deep and contained about 4 inches depth of the rooting medium. Each pit was covered with three panes of glass each 1 ft. 4 in. by 1 ft. 8 in. laid flush with the ground. Mounting the glass in a light wooden frame so that it is several inches above the ground, and sloped for drainage, is a suggested improvement. Some rooting occurred in these pits but the percentage,

coupled with the long time taken, was unsatisfactory, and lighting was thought to be insufficient. Larger pits on a less heavily shaded plot were tried but owing to the absence of wind breaks, with a lid resting on the soil the humidity could not be maintained high enough to prevent desiccation of the cuttings. It was realised that under true estate conditions the difficulties would be minimised, as situations could be chosen combining high atmospheric humidity, moderate but not excessive shade, and a well drained soil. Consequently, with the kind co-operation of Mr. C. de Verteuil Jnr. an experimental field propagator was constructed at La Vega Estate in the Montserrat district.

This propagator consisted of a nailed box of 1 inch cedar boards 6 ft. long by 3 ft. wide by 1½ ft. high without top or bottom. It was designed to rest on the ground and to have a glass-lighted cover, thus making a closed chamber of about 27 cu. ft. capacity. The first experiment was started in June 1933. A position was selected under medium cacao shade and a pit dug 3 ft. by 6 ft. by 6 in. deep. The pit was filled back to soil level, one half with drift sand from a river and in the other half the excavated soil was lightly replaced. The wooden frame was placed over the pit, and miscellaneous fan and chupon cuttings were set in the soil and in the sand. It must be noted that the sand was far from pure, containing a large amount of silt and micaceous particles. These media were unsatisfactory and insufficient drainage was provided by the pit. The cuttings kept fairly fresh above the soil, but no callus formed and the ends tended to rot although watering was cut down to a minimum. Even under these conditions however a few cuttings rooted. In this connection experiments have shown that

a medium of high water content, approaching a water-logged condition, often induces quicker rooting of cacao cuttings than a drier medium. On the other hand, soil is an unsatisfactory rooting medium as the ends tend to decay before rooting can take place.

In later experiments the pit was made deeper and with the floor sloping to an outlet drain. The floor was covered with coarse gravel upon which finer gravel, and above this, the rooting media were laid. For the second experiment four different media were used.

- A. Moss.
- B. White fine sand.
- C. White fine sand mixed in equal parts with river sand.
- D. Medium calcareous sand of the type used in routine propagation work at the College.

Uniform fan cuttings were used, all taken from one tree. 12 each in A and D, and 11 each in B and C.

Examined after 36 days.

A. *Moss*.—Cuttings had mostly kept green and had made large callus, but only two showed any signs of rooting, having each two small roots just emerging. Several cuttings had decayed.

B. *Fine Sand*.—All the cuttings were alive, seven retained some leaves, four were fairly well rooted.

C. *Fine Sand and River Sand*.—Cuttings mostly alive, only a few retained leaves, two fairly well rooted.

D. *Coarser Calcareous Sand*.—All cuttings alive, mostly with some leaves retained, but only one was rooted.

After a further 2-3 weeks all the cuttings in the moss had dropped their leaves or had died, the fine sand showed further cuttings rooted up to 7, the mixture also had two more rooted, and the calcareous sand had five cuttings with roots. The moss was clearly a poor medium. As in previous

trials with moss, the cuttings either decayed fairly quickly or made very large callus growth with feeble roots. The two pure sands were both good, the fine sand being much better than had been expected, and further trials in the propagators at the College have confirmed the value of this sand as a rooting medium. Admixture of the fine sand with silty river sand was clearly deleterious, and supported the general experience that mixed sands are of less value than pure sands of approximately uniform grain size. On account of the tendency for the fine grade sand to pack, direct watering of this grade was cut down to a minimum, only being done every 14 days. The moss, and the coarse sand were watered every three days. The fine sand appeared at a disadvantage unless first class cuttings were used, as with less vigorous cuttings there was a tendency towards leaf-yellowing, and rotting of the bases. Where second class cuttings only were obtainable the coarser calcareous sand yielded better results. Further batches of fan cuttings put in the field propagator in this sand gave a reasonable percentage of rooting within one month, the roots being just formed after this time. After a further period of one to two weeks the cuttings were potted into baskets, using a mixture of coarse sand and soil. The potted plants were kept in a hardening frame, similar to the propagator.

Throughout the rainy season of 1933 the field propagation experiments were handicapped by the lack of first class material for making cuttings. The excessive rains caused a set-back to the trees and there was practically no vigorous "general flush". Chupons also were scarce. It was not considered worth while to propagate other than select material so that experiments were carried out with small batches of cuttings from selected trees of high yield and quality. The cuttings successfully rooted have been planted out on the estate close to the propagator, so that in the near future they will be able to yield additional material for propagation.

THE VEGETATIVE PROPAGATION OF CACAO.

V.—Notes on the Dimorphic Branching Habit of Cacao.

BY E. E. PYKE.

THE possession of two distinct types of branches is characteristic of many trees, more especially of those of the tropics. In cacao this dimorphism is particularly well marked. In common with most other trees, the seedling axis is orthotropic and the lateral branches are plagiotropic. These laterals, however, have a characteristic origin. The axis of a cacao sapling grows under favourable conditions to a height of from three to four feet in the first year, at about which time further extension ceases and an apparent whorl of five radially arranged branches is formed, known collectively as the "jorquette." Each branch grows at an angle of 30° to 40° to the vertical and produces branches of

higher order, forming the "crown" of the young tree. Examination of the top of the seedling axis, just at the time of formation of the lateral branch buds shows that there is a rapid progressive reduction of the internodal lengths, sufficient to condense the open 3/8 spiral of the phyllotaxis into an apparent whorl. The uppermost leaves are not all developed, but are represented only by their stipules, which invest the group of buds.

The growth of the seedling axis up to the time of "jorqueting" takes place by a series of "flushes" with short pauses intervening. The rate of elongation during each flush is represented by a peaked curve, starting slowly, rising to a

maximum and then declining. This is also reflected in the size of the successive leaves of the flush and in the lengths of the internodes, so that there is a certain degree of condensation at the top of each flush. The condensation however of the internodes is generally much more marked at the top of the ultimate flush before the "jorquette" occurs, and this would appear to be of significance in the determination of the point of jorquetting.

The pause, during which the group of five lateral buds can be seen at the extreme tip of the stem, is often of rather longer duration than those between flushes, and when elongation is resumed, the five laterals grow out simultaneously, but one or two may be dominated by the others and may not develop to more than twigs. In addition to their plagiotropic habit, these branches have an entirely different phyllotaxis from the seedling axis and associated with it a different spatial relationship of the leaves to the stem. Thus in the seedling axis, or "chupon", the leaves are disposed radially, the phyllotaxis being a $3/8$ spiral. In the plagiotropic shoots the phyllotaxis is $\frac{1}{2}$ i.e., the leaves are arranged in two ranks, and furthermore the petioles are twisted so that the two ranks of leaves and the stem all lie in a plane. This property gives the popular names of "fan" or "palm" branches to these shoots. As the sapling grows older the original five (or fewer) branches of the jorquette form the main branch system of the tree, and normally this consists entirely of fan branches. Frequently the main trunk (the original chupon axis) sends up a sucker from just below the jorquette, which may grow up for several feet and jorquette in its turn, so that another branch system is formed—making a so-called two-storey tree. In large trees this has sometimes been repeated several times. In addition, the cacao tree usually sends suckers from the base of the trunk, although observations indicate considerable variability between trees in this quality.

These suckers and those, in general, from any part of the chupon trunk, are themselves chupons. Thus, as a general rule, fans give rise to fans, and chupons to chupons, except in the special case of the jorquette. This has an important bearing upon propagation by cuttings. Frequently only fan material is present for making an initial isolation of a strain, but the ultimate advantages of establishing strains in the form of chupons are great. The question arose as to whether it would be preferable to wait until each selected tree had thrown sufficient chupons to enable small clones of chupon cuttings to be established (several trees have not produced any chupons during more than one year's observation), or whether to form clones from fan cuttings, or by budding from fan buds, in the hope of being able to effect a change-over to the chupon habit within a reasonable time, by some form of manipulation. The generally unfavourable season of 1933 for vegetative growth, especially of vigorous chupons, left no alternative to the second method in most cases, so that clones of budded seedling stocks, and fan branch cuttings

were made from several trees of the I.C. selection series. The expectation of being able to induce the change from fan to chupon was based on observations of a number of deviations from the normal dimorphic habit, on trees of various ages and habitat, from which it appeared that under suitable conditions the rigid distinction between the orthotropic chupon and the plagiotropic fan broke down and transitional forms showing intermediate characters could occur. In addition, the complete transition from chupon to fan without a jorquette, and the converse case of a fan turning into a chupon, were both observed. It will be convenient to describe some cases of naturally occurring plasticity, and then to give an account of experimental work.

Naturally Occurring Variations of Habit.

Chupons on Fans.—These are observed fairly frequently in cacao estates on mature trees. Individual trees appear to have a tendency towards production of chupons. They are often found growing on cankered branches but they also occur on healthy branches. Trees have been observed with over a dozen true chupons growing on the main branches, sometimes showing the zone of roots at their bases which is characteristic of the suckers growing at ground level. It is remarkable that chupons were rarely found on the budded trees at River Estate. In these, apart from the rootstock the whole tree was derived from a fan shoot. Vigorous suckers were formed on the trunk and branches but were nearly always true fans, the few exceptions were in some cases chupons, but were mostly transitional forms.

In young seedling trees, aged a few years, chupons were never observed occurring naturally on the fan branches. Mention must however be made of the cases of transition from a fan branch to a chupon which occurred naturally on a young fan tree and a layered fan cutting respectively. The fan tree was vegetatively propagated from a layer, and about a year and a half after planting out it formed a feeble fan shoot from just above soil level, which ceased growth after a flush of a few inches. When growth was resumed the terminal bud grew out into a vigorous chupon which formed a jorquette. The original fan branch system was pruned right back to allow the chupon to re-form the tree. After pruning, further chupons grew directly from the fan stump. The case of the layered fan cutting was similar, and undoubted transitions of the terminal bud were also noticed on some of the manipulated fan cuttings and layer shoots.

Fans on Chupons.—The converse case of a direct transition of a terminal bud from a chupon to a fan, without a jorquette being formed, was also observed. Several hybrid seedlings from the second generation of the crossing of cacao and *Theobroma pentagona* exhibited this transition, which in some was abrupt and in others gradual. In these the axis was initially a chupon and the phyllotaxis gradually uncoiled, so to speak,

together with progressive shortening of the petioles, until the upper region of the stem exhibited the characters of a true fan. In this connection the true-bred *pentagona* trees examined showed no evidence of having jorquetted and suckers growing on the trunks had the fan branch phyllotaxis, although having the orthotropic habit and long petioles of a chupon.

In *Forastero cacao*, a direct formation of a fan from a chupon was observed on a layered chupon stem, which sent one fan shoot in addition to several chupons. Further cases have not been observed, although suckers suggesting transitional forms were occasionally met with growing from the bases of mature trees.

Experimental Work.

Most of the observed cases of chupons growing upon fan branches occurred on mature trees growing in plantations. For the purpose of establishing nurseries of chupons from fan cuttings it would be necessary to obtain the transition at a much younger stage, and in order to accomplish this in a high proportion of cases trials of various manipulative treatments were made on the first batch of vegetatively propagated material established.

The experimental methods tried were of four types:—

1. *Pruning*.—To alter nutritional conditions of existing buds.
2. *Ring-Barking*.—To alter nutritional conditions of existing buds.
3. *Layering*.—To alter gravitational environment of existing buds.
4. *Production of Adventitious Buds*.

The trees used were seedlings, from 1 to 3½ years old, fan cuttings aged 1½ to 2 years, and rooted fan shoots from layers, established for about 1 year. In addition, older trees were subjected to pruning and ring-barking of the main branches.

PRUNING.—(a) *Seedling Trees*.—The frequent production of chupons upon the fan branches of heavily pruned mature trees suggested the pruning of young trees to encourage chupons. A number of 3 year old seedlings were pruned, some were cut back very heavily, leaving only short stubs from the jorquette, and others were given a lighter pruning, in that one side only of the tree was heavily cut back. In one case the canopy was of course entirely removed, and in the other it was reduced by about one-half. In the case of the heavily pruned trees vigorous new shoots were formed near the cut ends of the branches. In one tree these appeared to be mostly fans and in the other, chupons. However on both trees there were a number of shoots which could not with certainty be classed as either. While mostly resembling fans in their phyllotaxis, which approximated to a two-ranked arrangement, they had an orthotropic habit and fairly long petioles, in these respects resembling chupons. These were called "pseudo-chupons" and on resuming growth after a pause, the new flushes appeared to be normal

chupons. Hence both trees soon produced a considerable number of chupons on their fan branch systems as a result of heavy cutting back. These shoots were of first class quality for using as cuttings. The less heavily pruned trees also showed a tendency to produce "pseudo-chupons" which later turned into true chupons, but the response was much less vigorous than on the hard pruned trees.

(b) *Fan Cuttings and Layers*.—The number of these trees available was unfortunately very limited, there were only four fan cuttings considered of sufficient growth for treatment, and the same number of fan layer shoots. The fan cuttings and layer shoots formed plants of quite a different habit from seedlings or chupon cuttings. They made low-branching bushes and in accordance with the two-ranked leaf arrangement the plants at first tended to grow in virtually two dimensions only, unless trained.

The pruning adopted was to cut back the lower branches to stubs of about six inches long, in order to encourage the growth of vigorous shoots from them. At the same time the top branches were slightly pruned, so as to admit more light to the lower ones. The method was successful in that vigorous shoots were formed, but they were true fans. Pruning in conjunction with completely ring-barking the stem below the pruned branches was more effective in inducing chupons, and the results are given below under "Ring-barking."

(c) *Young Budded Plants*.—Van Hall ("Cocoa" 2nd Edition, page 132) describes a method for obtaining chupons from the scion of a fan-budded plant by cutting back the scion, when 6-10 cms. long, to a short stub of about one centimetre, from which chupons were said to develop. The method was tried on young budded seedlings in a nursery at the College and on similar plants budded at stake on an estate. In nearly all cases the treatment resulted in a very great check to the plants and several died. When growth was resumed usually two or three short fan shoots grew from the stub. In the estate trees these remained as fans, but on a few of the nursery plants they turned into chupons. On account of the slow and uncertain response, and the possibility of losing plants, this method for obtaining chupons was not considered very useful unless a surplus of budded plants was available.

RING-BARKING.—This consisted of the removal of a complete ring of bark, from a stem or branch, of a width of 1 to 2 cms. Previous work showed that on young cacao seedlings the ring, if not wider than 2 cms. was repaired within a few months and no damage was suffered by the isolated portion. At the same time a strong shoot was frequently sent up from just below the ring. Thus the effect of ring-barking the main stem was similar to that of stooling, except that one or two shoots were formed instead of several. It was thought that possibly the concentration of effort in a few vigorous shoots would provide the conditions for the transition from fan to chupon, if a young fan tree was ring-barked.

(a) *Cuttings and Layers*.—Two fan cuttings, and two fan layer plants were ringed on the stem a few inches above soil level. The first cutting ringed sent three fans and one true chupon from below the ring. The chupon died back at the top but sent another chupon from the base. One of the fans was allowed to grow for a few weeks and was then cut back in the hope of its also making a chupon, but further fans only were formed. The other cutting was ringed in conjunction with hard pruning of the lower branches. In this case no shoots were sent from below the ring, but the lowest branch sent five strong fans, one of which after three inches growth turned into a chupon. Of the two ring-barked layer shoots one showed no response for several months during which time the ring completely healed. Eventually however a chupon grew from the base of the stem below the ring. In the other plant, besides ringing, the lowermost branch was pruned. The pruned branch sent four fans, and the stem below the ring sent two chupons and three fans, all of vigorous growth. Thus all four plants manipulated by ringing eventually formed chupons, in three cases on the stem below the ring and in one case on a pruned branch above it.

Four plants, one cutting and three layer shoots, were not ringed and could be considered as controls. The cutting and two of the layer shoots produced no chupons, but the third layer sent a fan from near soil level which with no manipulation turned into a chupon after a few inches growth. As this grew the rest of the plant was gradually cut back, so that it consisted of a fan stump with a main chupon growing from it. Several more chupons were formed upon this fan stump from time to time.

(b) *Mature Trees*.—The frequent formation of chupons after pruning the crown of cacao trees and their sporadic occurrence on the branches often, it seemed, near extensive canker lesions, suggested the possibility of obtaining chupons artificially by ringing fan branches. A considerable number of trees were so treated but although a shoot frequently appeared behind the ring it was in all observed cases a fan shoot. The response to constriction by binding the stem tightly with galvanized iron wire was even less marked, and results are still awaited.

LAYERING.—The method adopted was to remove nearly all the leaves and to peg the young plant along the ground. Besides the effect on the tropisms of the bud, this represents a heavy pruning. One fan cutting was layered during the rainy season of 1933, the others being held over

until the drier weather. The response of new shoots was immediate but they were all fans. Unfortunately the majority rotted during the extremely wet weather, and a further crop of fan shoots was formed later in the season. One of these turned into a chupon which formed a jorquette at a height of about 1 foot. During the dry season of 1934 a considerable number of fan cuttings will be available for layering, and also the fan scions of budded plants.

Summary of Manipulation Results.—Of five plants manipulated either by layering, ring-barking, pruning or a combination of the last two, four produced one or more chupons. Of four plants not manipulated in any way only one formed chupons. Although the lack of material sufficiently advanced in growth severely limited the scale of the experiment the preliminary results obtained indicate that no difficulty should be met with in obtaining chupon nursery material from clones originally propagated as fans. The combination of ring-barking and pruning vigorous fan cuttings at an age of about 1½ years promises a method of converting them into chupon plants which could then be either stooled or layered *in situ* or propagated as cuttings.

PRODUCTION OF ADVENTITIOUS BUDS.—The foregoing results indicate that the terminal bud of a shoot can change over from fan to chupon, and the reverse has also been observed. There is also the possibility that a chupon might arise from an adventitious bud. Several trials have been made unsuccessfully to induce adventitious buds from callus on the cut ends of branches and hardwood cuttings. Both vigorous chupon and fan branches were cut with a sharp knife and the cut surfaces maintained in a humid atmosphere by covering with test-tubes plugged with cotton wool. The axillary buds at the top of the stem in the region of the cut were either left to develop, picked off after swelling, or were completely removed before swelling. The callus which developed was in some cases left uninjured, and in others pared off or pricked. In no case however was an adventitious bud formed. In the hardwood fan cuttings the top callus was not injured by pricking or paring, to avoid undue stimulation of callus growth, with subsequent depletion of the slender food reserves. No adventitious buds were formed upon the cuttings. In softwood cuttings which had been cut back in preparation, fairly large callus frequently developed on the cut surface and in some cases buds pushed at the extreme tip. In all cases however these were found to be axillary buds.

A PRELIMINARY SURVEY OF PIGMENT FACTORS IN CACAO.

BY F. J. POUND.

THE problems of crop improvement that face the cacao industry to-day concern not only the efficiency of yield but also the intrinsic quality of the commercial product. The presence of a red

or purple pigment in the "nibs" or cotyledons detracts from quality, since it is generally held to be associated with bitter principles which have to be removed in curing or roasting before the beans

can be made palatable. Pigmentation, though varying widely in extent, is a general characteristic of the beans of Forastero cacaos, whilst Criollo types undoubtedly parental to the complex have completely unpigmented beans. This being so it is evident that in selection of superior Forastero types preference, yield and other factors being equal, should be given to those with the lightest coloured cotyledons, and it follows that any means of diagnosing pale beans from other characters of the plant producing them must be of importance.

Genetic factors controlling the expression of pigments in one part of a plant frequently control also their expression in other parts, and for this reason correlations have been sought between degrees of pigmentation in the various parts of the cacao tree. Pigments occur in the young leaves before maturity, in the outer tissues of the pod, and to a varying extent in the sepals and at the base of the style in the flower. In some cases there is a certain amount at the junction of the petiole with the stem (the so-called "axil spot") easily recognized in the seedling stage, but in the mature tree often less obvious owing to supplementary reddening of the petioles.

Attempts to establish correlations from the study of mature trees are noted elsewhere in this Report (see "Student Investigations"). In conjunction with them, studies have been made of the seedling progenies of certain known trees, and the results are here presented. From the outset it was realized that inheritance of pigmentation was likely to prove highly complex, since it has probably been introduced into the hybrid population from several different sources. At the present stage of these essentially economic researches no thorough genetic analysis is possible, and the results are given merely for what they may be worth in defining more precisely the problems that are ultimately to be solved.

Inheritance of Pigment in the Bean.

A great deal of evidence exists to show that the presence of pigment in the cotyledons of cacao is a dominant character. Direct experimental demonstration has been given for certain Java cacaos by Wellensiek (1). According to Van Hall (Cacao 2nd Edn. p. 329) it has been noticed both in Venezuela and in Java that "even when surrounded by Forastero trees the Criollo always gives an offspring consisting of pure Criollo trees". Whatever the explanation of this behaviour, there appears to be no good evidence for the existence of any dominant white type, and the general experience wherever Criollo plantations have become interplanted with Forastero types has been of deterioration in the quality of the product, due at least in part to the increased proportion of pigmented beans following natural crossing. Within the Forastero complex as a whole, a very small proportion of white beans is still found, but their rarity indicates that the dominant pigment factors introduced by purple-beaned ancestors are multiple and additive. Among the purple beans there are some so heavily pigmented as to appear

almost black, and others completely coloured but of various paler shades. In some the pigmentation is developed at an early stage in the embryo, whilst in others it develops late and a genetically dark bean may be quite pale just before maturity. Some are merely flushed with pigment, and some are white centred with a purple edge when seen in section. For practical purposes it is convenient to distinguish three classes, purple, light and white. From the greater number of Forastero trees only purple beans are obtained. A few trees segregate purple, light and white beans within the pod, and a very few give wholly light or white. On germination, the cotyledons emerge with the same relative degree of pigmentation that they had in the pod, though now partly masked by green, and it is fairly easy to separate the seedlings into two groups, "purple" on the one hand and "light" (including the pure white) on the other. The progenies of some trees examined in this way show very close approximations to a segregation ratio of 3 purple to 1 light (Table 5).

Table 5.

Tree.	Treat- ment.	Ratio of seedlings.	Expecta- tion.
St. Augustine 9	Hand selfed	249 : 86	251 : 84
St. Augustine 8	Hand selfed	225 : 77	226.5 : 75.5
St. Augustine 6	Crossed by 8	228 : 76	228 : 76

At the same time neither the purple nor the light class is uniform, and ratios approximating to 9 : 3 : 3 : 1 have been found when ripe beans from these same trees have been examined by cutting them longitudinally through the cotyledons. Unfortunately beans examined in this way will not subsequently germinate. These observations agree closely with those of Wellensiek (*loc. cit.*) and show that the behaviour of certain Criollo-Forastero hybrids in Java is paralleled by that of some members of what we call the Trinitario complex. In both cases there is evidently a single basic pigment factor-pair with one or probably more pairs of modifying genes. The segregation, however, is not always so simple, as will appear later.

Inheritance of Pigment in the Pod.

The range of pigmentation in the external tissues of the pod has been described and illustrated in the Second Annual Report on Cacao Research. It was there shown that a practically continuous series of reds occur on two distinct bases, distinguished as "green" and "white." Among 2,125 trees classified by pod colour there were approximately 60 per cent. with more or less red pigment in the pod and 32 per cent. with none. The unpigmented class is therefore too large to suggest without further analysis and experiment that presence of pigment is always dominant to its absence in the

pod, as it appears to be in the cotyledons. Fully ripe pods can be classified into "red" and "yellow", the latter class including those flushed slightly with pigment before maturity as well as those quite unpigmented. There is a correlation between red pod and "axil spot" which will be mentioned later.

Inheritance of Pigment in the Flush.

The colour of the flush has hitherto received little attention, and it presents great difficulties in the classification of the grades of pigmentation that occur. The present observations were made on seedlings about 9 months old. Freeman (Student Investigations) used as an index the highest order of veins in which pigment could be clearly seen in the young leaf, but this method proved less successful for seedlings than for the mature trees on which he was working. Intense colour in the third order of veins often gave the same effect as less intense colour extending to the second order. At first the leaves were judged when about 4 inches long, since after that stage as the leaf matures the colour changes through bronze to green. It was found, however, that in some seedlings the flush started almost pigmentless and darkened as the leaves grew, whilst in others it started with pigmentation that did not intensify with age. At a length of 3-4 inches some changed rapidly to dark bronze and then green, whilst others of identical pigmentation retained a bright red colour almost to maturity. Finally a system of arbitrary marking was adopted, very pale flush being marked 1; normal bronze flush, 2; flush distinctly red as opposed to bronze, 3; flush very red, often with the petioles coloured, 4. The results are of interest mainly in connection with cotyledon colour, and will therefore be given in a later section.

Inheritance of Axil Spot.

This character was studied by Harland and Frecheville (2), and found to be governed by two pairs of genes and correlated with pod colour, trees from which the pods ripen red showing axil spot.

Experimental Data on Correlations.

In this section the experimental evidence will be given in detail, and conclusions drawn from each experiment in turn. The observations fall into two groups, those where bean pigment and flush are considered in the absence of pod pigment and axil spot, and those where flush and axil spot are considered with bean pigment constant. The important case where bean pigment and axil spot both segregate has been imperfectly investigated as yet.

COTYLEDON COLOUR AND FLUSH.

Case 1.—Tree No. 9, St. Augustine has a green pod, slightly flushed with red but ripening yellow, and no axil spot. Eleven pods were set by controlled self pollination. 335 seedlings segregated for cotyledon colour in a 3 : 1 ratio (249 : 86). Plot 1 was planted with "light" seedlings only,

from eight pods, plot 2 with complete progenies of three pods. Nursery conditions were not suitable for classification of flush colours, but it was quite apparent that the range of flush pigments was substantially the same in both plots. No axil spot was shown throughout. Conclusion:—light flush need not be associated with light cotyledons, since the plot containing no "purple" seedlings exhibited the full range of flush colours.

Case 2.—Tree No. 8, St. Augustine has a "white base" pod, completely unpigmented, although it is a sib of No. 9, and no axil spot. Eight pods set from controlled self-pollinations. The 302 seedlings segregated for cotyledon colour in a 3 : 1 ratio (225 : 77). These seedlings were not used further, but the constitution is important from the use of this tree as male parent in subsequent cases.

Case 3.—Tree No. 6, St. Augustine has an unpigmented "white base" pod like No. 8 and no axil spot. Being self-incompatible it had to be pollinated by No. 8, and 10 pods were obtained. 304 seedlings segregated for cotyledon colour in a 3 : 1 ratio (228 : 76), and the tree must therefore have the same constitution in this respect as No. 8. All seedlings were planted in a well-manured nursery, with side shade from bananas. There was no axil spot throughout. Some seedlings died from insect attack, but 281 were classified by flush colour at about 9 months old, by the method described above, with the result shown in Table 6.

Table 6.

Flush Index.	Purple cotyledons.	Light cotyledons.	Total.
1	19	0	19
2	119	32	151
3	71	34	105
4	4	2	6
Average flush value	2.28	2.56	

Conclusion:—The seedlings with light cotyledons have if anything a slightly darker flush than those with purple cotyledons. The difference is probably not significant, but in any case there is no evidence that light flush is associated with light beans.

Case 4.—Tree No. 4, St. Augustine has a "green base" unpigmented pod and no axil spot. Like No. 6 it is self-incompatible, but pods were obtained by pollinating from Tree 8. 295 seedlings segregated for cotyledon colour into 207 purple : 88 light. Expectation is 221 : 74, and the difference is significant. Other cases are under observation in which although no systematic examination of seedlings has been made, segregation in the pod departs even more widely from a 3 : 1 ratio and the excess of light beans cannot be ascribed to crossing by neighbouring trees. For present purposes,

however, this observation is by the way. The classification of 281 seedlings by flush pigmentation gave the results shown in Table 7.

Table 7.

Flush Index.	Purple cotyledons.	Light cotyledons.	Total.
1	20	4	24
2	115	50	165
3	57	29	86
4	5	1	6
Average flush value	2.24	2.32	

Again there is a slight but probably accidental bias *against* any association of light flush with light beans.

Case 5.—Tree No. 7, St. Augustine has "white base" pods with no pigment and no axil spot. Self-incompatible, it sets pods with pollen from Tree 8, and in the progeny no light beans occur, so that it must be homozygous for the basal pigment factor in the bean. The range of flush pigments is similar to that obtained where purple and light beans segregate, and is given as additional evidence of the fact that pigment in the young leaves is independent of bean pigment factors.

Flush Index.	Purple cotyledons.
1	4
2	52
3	25
4	5
Average flush value	2.36

From Cases 1, 3, 4 and 5 it may fairly be concluded that, so far as the progeny of Trinitario trees with unpigmented pods is concerned, the factors producing pigment in the young foliage leaves are not those producing pigment in the cotyledons, neither is there any evidence of linkage between the two sets.

FLUSH AND AXIL SPOT.

Correlations between pod colour, flush and axil spot are for our present purposes of secondary interest. That between pod colour and axil spot has been mentioned above. Harland and Frecheville (*loc. cit.*) also state that trees with red pods give a darker flush than trees with pods ripening yellow. The factors responsible for slight flushing of the unripe pods do not appear to produce axil spot, so that it would seem that the axil spot genes may themselves act as intensifiers of pod pigment. Freeman (*loc. cit.*) found a positive correlation coefficient of 0.80 between axil spot and flush colour, as well as a coefficient of 0.85 between flush colour and pod colour. The general conclusion from the fragmentary evidence available to date is that there is some association between the pigments in all these three parts of the plant, but not a simple one.

Case 6.—Tree No. 5, St. Augustine has partially pigmented pods and axil spot is present. From the cross with Tree 8, 310 seedlings were obtained. All showed purple cotyledons, from which it must be concluded that Tree 5 is homozygous for the basal pigment factor in the beans. Axil spot in the young stage (when it is best seen) was observed to vary greatly in intensity. In some cases it was so faint as to be barely discernible, and a few classified as "no spot" may actually have possessed very faint spot. The observed segregation was 145 with spot: 165 without, a fairly close approximation to an expectation on a 1:1 basis of 155:155, especially if allowance is made for possible errors in missing faint spots. Since Tree 8 apparently carries no spot factor, Tree 5 would appear to be heterozygous in this respect. The classification of 289 seedlings by flush gave the results shown in Table 8.

Table 8.

Flush Index.	Axil spot present.	Axil spot absent.	Total.
1	0	5	5
2	0	49	49
3	37	88	125
4	103	7	110
Average flush value	3.74	2.65	

The flush is generally more intense than in former cases, but the striking feature is the intensity where axil spot is present, the majority grading 4 and none grading below 3. In some cases where spot was judged absent the leaves were very dark red and the petioles slightly pigmented, suggesting again that in a few cases "spot" may have been present but unexpressed. When allowance is made for this possibility, the average figure of 2.65 for the seedlings with spot absent agrees well with those obtained from unpigmented pods.

Case 7.—Twenty-two seedlings were raised from white beans from a pod of Venezuelan Criollo. The pod was very slightly flushed with red. A very slight axil spot was found in 12 of the plants, and although the general flush colour was lighter than in the plants of Case 6 there was the same correlation of dark flush with axil spot as in that experiment (Table 9).

Table 9.

Flush Index.	Slight axil spot.	No axil spot.	Total.
1	1	3	4
2	2	6	8
3	8	0	8
4	1	1	2
Average flush value	2.75	1.90	

Case 8.—Tree No. 36 has a dark red pod and axil spot, and its progeny segregate in both cotyledon colour and axil spot. As yet very few seedlings have been raised, and none are old enough to be classified for flush. It is interesting however to note that to date no seedling with light cotyledons has shown axil spot, so that possibly in this particular gene complex the two are negatively associated. This case will receive further attention.

Discussion.

It is almost impossible to discuss the inheritance of any character in Forastero Cacao, or at least in that section called Trinitario, without some reference to the ancestry of the complex, and conclusions are greatly hampered by our ignorance of the parental types in a pure condition. There is fair evidence for the assumption that white bean types have hybridised with purple bean types and on both sides there was certainly more than one parental type.

Of the Criollo or white bean parents the most important contributor is probably the Venezuelan Caracas cacao which exists normally with dark red pods. Our knowledge of flush pigments in this type is vague so that it cannot be stated whether the trees always flush red and possess axil spot. The two other possible contributors namely Nicaraguan Criollo and *Theobroma pentagona* occur in Trinidad as recent introductions and are apparently pure. Both of these types show completely pigmentless leaf flushes and at the most only slightly flushed pods.

The purple bean genotypes are even more obscure. The most important seems likely to have been a true breeding Amelonado type closely resembling that cultivated extensively in West Africa with normally a yellow pod. The supposedly true breeding Cacao Nacional of Ecuador has pods very similar to many of the Angoleta and Cundeamor types of the complex but where, if ever, this type entered the complex is not clear. Again it is not known how far the Calabacillo or the extreme type called *Th. sphaerocarpa* by Chevalier represent true parental types or merely segregates outside the range of parental characters, a feature well known to result from species crosses. Calabacillo does appear mixed with Amelonado in Brazil where higher types are not present. Both however are stated to have pigmentless pods.

The broad hypothesis which emerges is that of possible parental types known, only the Caracas cacao introduced pod pigments, a fact which

probably accounts for van Buuren's (3) negative correlation, between pod colour and bean colour in the case of a 'Cundeamor-Forastero' progeny in Ceylon.

It must not be forgotten that even in Caracas cacao a few unpigmented pod types occur which produce only white beans and also in Java, Van Hall states that a white seeded 'Porcelaine' variety was present before the introduction of Forastero types. In spite of its white seeds the pods have the outward appearance of Amelonado. Such facts as these illustrate the danger of regarding even the supposed parental types as true breeding or unchangeable.

Assuming that bean pigments entered from pigmentless pods and pod pigments from white bean types it is not surprising to find a lack of linkage between those genes responsible for bean and pod pigments in the complex. That there should be no correlation between bean pigment and flush colour is difficult to explain in the absence of detailed knowledge concerning the flush pigments of the hypothetical parent types. A number of *leiocarpa* seedlings from the backwoods of Surinam have a slight but quite definite range of flush colour and even seedlings of the ill-defined 'Trinidad Criollo' do not show a constant flush pigment. Neither of these sets of seedlings shows any evidence of axil spot and in the complex, trees bearing pigmentless pods, irrespective of bean colour have never been found with this character. Further, trees bearing pigmentless pods irrespective again of bean colour invariably flush light and occasionally without obvious pigment at all.

Thus as far as can be gathered from the meagre data obtainable, axil spot entered the complex with the dark red pod and white seeds; and once there, appears to act as an intensifier for flush pigment. It follows that only by a small chance will a light flush in the complex proper indicate a potential bearer of white seeds, or a dark flush a purple seeded tree.

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THE VARIABILITY OF BUDDED CACAO.

By F. J. POUND.

ONE of the basic aims of the Cacao Research Scheme is to find methods of assuring uniformity in the cacao field of the future, and it has been accepted that some method of vegetative propagation will be necessary to that end. From analogy with the fruit crops of temperate regions it has been argued that cacao budded on seedling

stocks is probably far from uniform in behaviour, on account of the variation introduced by the heterogeneous root system. Until seedling stocks and clonal stocks can be compared side by side, this point cannot be finally proved, since there is no standard available for distinguishing variation due to stock from variation due to soil conditions.

At the same time, the whole practice of budding rests on the assumption that budded progenies on seedling stocks are less variable than seedling progenies on their own roots. There exists in Trinidad one opportunity of estimating quantitatively the reduction of variability that may be expected from the method, and that opportunity has been taken in this paper, in which budded and seedling progenies of the same trees are compared and some estimates advanced of the variation within the budded clones.

The Material Analysed.

The only suitable material available consists of a field of budded trees situated at the Cacao Experiment Station of the Government of Trinidad and Tobago, and once again we are indebted to the Director of Agriculture for permission to use his Department's records. This field, known as the "Propagation Field," was laid out in 1914 for two purposes. One was to compare the relative yields of budded and seedling trees under shade and no-shade conditions, and the other was to compare the yields of trees budded under two different conditions. The field is divided into six blocks by lines running north and south, the order and treatments of the blocks from east to west being:—

- A. Budded by method A. Shaded with immortal.
- B. Budded by method B. Shaded with immortal.
- C. Seedlings. Shaded with immortal.
- D. Grafted. Shaded with immortal.
- E. Budded by method A. No shade.
- F. Budded by method B. No shade.

Each block has a capacity of 280 trees, and contains 28 clones or seedlings progenies as the case may be. The same 28 parent trees are represented in every block, the seedlings of progeny 1 in the case of each of the blocks C and F being from beans of the tree which supplied budwood or scions for clone 1 in each of the blocks A, B, D and E, and so on for all the other progenies and clones. There is no randomization within the blocks. The ten trees forming each clone (or progeny) occur in one straight line, running, and numbered, from north to south. The blocks are actually 7 clones wide (E. to W.) and 4 clones deep (N. to S.) but in analysis have been regarded as 28 clones wide and one clone deep. In other words they are considered as consisting of ten "rows", all the first trees of each clone or progeny together forming row 1, all the second trees row 2, and so on.

A record of the number of pods harvested from each tree from the commencement of bearing has been kept and for the present analysis the average annual yield of each tree for the five-year period 1926-1931 has been used.

As a groundwork on which to base comparisons, the analysis of the seedling blocks will be discussed first. Then the figures for variance obtained from

the budded blocks will be compared with them. In this way it is hoped to discover whether the use of clonal material causes any appreciable reduction in variance.

The Variance of Bearing.

The Method of Analysis.—The total variance may be divided into two portions, one showing the variance between clone and clone, and the remainder expressing the whole variation within clones.

Provided the soil is evenly fertile over the whole block, this latter variation will be entirely ascribable to the different bearing capacities of trees within the same clone. When the soil is heterogeneous, the variance within clones may appear greater than it actually is. In this field, only a fertility variation from north to south can be detected on account of the layout. This is expressed as the "variance between rows." In no case does this fertility affect the result so that in the discussion it is neglected.

The Analysis of the Two Seedling Plots.—Tables 10 and 11 give the Analysis of Variance for blocks C and F:—

Table 10.

Analysis of Variance of Block C.
(Mean Yield per Tree=22½ Pods.)

Due to	D.F.	Sum of Squares.	Mean Square.
Between Progenies	27	30,648	1,135
Within Progenies ..	252	70,594	280
Between Rows ..	9	1,211	134.6
Residual ..	243	69,383	285.5
Total ..	279	101,242	362

Table 11.

Analysis of Variance of Block F.
(Mean Yield per Tree=18 Pods.)

Due to	D.F.	Sum of Squares.	Mean Square.
Between Progenies	27	26,022	964
Within Progenies ..	252	77,709	308.4
Between Rows ..	9	895	99.4
Residual ..	243	76,814	316
Total ..	279	103,731	372

The two tables compare very favourably with one another. The larger total variance is found in block F, which has the smaller yield. In both cases, the variance *between* progenies is very significantly different from the variance *within* progenies, which expresses the fact that some progenies give significantly higher yields than others. The variance ascribable to soil heterogeneity is in neither case appreciable,

The Analysis of the Three Budded Blocks.—Tables 12, 13 and 14 give the Analysis for blocks A B and E.

Table 12.

Analysis of Variance of Block A.
(Mean Yield per Tree=24 Pods.)

Due to	D.F.	Sum of Squares.	Mean Square.
Between Clones ..	27	20,009	741
Within Clones ..	252	60,028	238
Between Rows ..	9	1,175	130.5
Residual ..	243	58,853	242
Total ..	279	80,037	287

Table 13.

Analysis of Variance of Block B.
(Mean Yield per Tree=22 Pods.)

Due to	D.F.	Sum of Squares.	Mean Square.
Between Clones ..	27	20,754	769
Within Clones ..	252	35,661	142
Between Rows ..	9	711	79
Residual ..	243	34,950	144
Total ..	279	56,415	181

Table 14.

Analysis of Variance of Block E.
(Mean Yield per Tree=18 Pods.)

Due to	D.F.	Sum of Squares.	Mean Square.
Between Clones ..	27	35,684	1,322
Within Clones ..	252	55,059	219
Between Rows ..	9	4,943	549
Residual ..	243	50,116	206
Total ..	279	90,743	325

Although the variances differ rather more than in the seedling blocks, the magnitudes are generally of the same order. In each block, the variance between clones is significantly different from the variance within clones. In two cases the variance ascribable to soil heterogeneity is negligible, and in the third it is so small that the residual variance within clones is not appreciably affected.

The lowest variance "within progenies" for the seedlings is 280 while the highest for "within clones" is 238, showing that although the tree to tree variability after budding is significantly large yet it is appreciably less than for seedlings. In other words, budding may be expected to reduce the tree to tree variance.

The Analysis of Healthy Trees in Blocks A and B.—The variance between trees of the same clone in the field may be largely due to the variable seedling rootstocks on which scions were budded. Some will naturally be more delicate than others owing to natural segregation, some will be suited to the bud which is worked on them while others may show varying degrees of incompatibility. It follows that one would expect more failures in the budded plots than among the seedlings and this expectation is realized.

In some cases the original trees have died, while others are dwarfed, diseased or otherwise moribund. The number of such trees is between 20 and 30 per cent. of the whole population. Given a compatible rootstock which is genetically vigorous, budded trees should then be more uniformly healthy.

The Analyses of variance for two blocks have been worked out using only seven healthy trees chosen at random from each clone. Tables 15 and 16 show that the variance within clones is now substantially reduced.

Table 15.

Analysis of Variance of Block A. (Healthy Trees.)

Due to	D.F.	Sum of Squares.	Mean Square.
Between Clones ..	27	28,252	1,046
Within Clones ..	168	23,514	140
Between Rows ..	6	643	107
Residual ..	162	22,871	141
Total ..	195	51,766	265

Table 16.

Analysis of Variance of Block B. (Healthy Trees.)

Due to	D.F.	Sum of Squares.	Mean Square.
Between Clones ..	27	12,868	476.6
Within Clones ..	168	14,630	87
Between Rows ..	6	288	48
Residual ..	162	14,342	88.5
Total ..	195	27,498	141

Thus, in block A, the total variance is only 265 as against 287 previously. The residual variance is very much reduced, being only 141 compared with 242 for the complete plot. This corresponds to a decrease of more than 40 per cent.

Similarly, in block B, the total variance decreases from 181 to 141, and the residual variance from 144 to 88.5. This corresponds to a decrease of 35 per cent.

If the diseased or moribund trees are at all correlated with incompatibility between stock and scion this incompatibility will be no mean factor in budding practices.

Direct Comparison of Budded and Seedling Blocks under Similar Conditions.—Since blocks B and C are in the middle of the shaded portion A, B, C and D, and their average yields are the same, they provide material for a direct comparison between budded and seedling trees. They are adjacent blocks, and therefore the soil factor, which we cannot estimate, is probably reduced to a minimum. From the tables it is evident that the total variance of block B is about half that of block C, and the same ratio exists between the residual variances.

Similarly, a comparison of the unshaded blocks E and F shows that the residual variance of the budded block is only 64 per cent. of that of the seedling block.

General Conclusions on Bearing.—The working of genetically uniform budwood on to seedling stocks does not result in a clone which gives a very uniform yield, even when records over five years are averaged. This may be due largely to the variability introduced by the seedling rootstocks. However, compared with seedlings of the same age and from the same parent trees as the budwood, the variation in the number of pods produced per annum is reduced by more than 30 per cent.

It follows that the production of genetically uniform rootstocks by some vegetative means should still further reduce the residual variance of budded clones. The possible occurrence of scion rooting has not been overlooked but no evidence of this can be found. The budding was usually done at 12 inches from the soil and this would tend to prevent scion rooting.

The Variance of Pod Value.

For block A an analysis of pod value was made over those clones which gave sufficient pods at the three consecutive harvests from January to March, 1933. The January, February and March pickings happened to be the largest for the year from most clones and as the season in 1933 was comparatively wet, the seasonal effect on pod size will be very slight. In the first part of the analysis an attempt has been made to compare the clone of ten trees, as a unit, with a single high bearing tree situated elsewhere on the same estate. The figures for these high bearing trees have already been worked out in the analysis of the Genetic Constitution of the Cacao Crop (*First and Second Reports*).

Only twenty-four clones gave sufficient pods (more than 50) for a useful analysis. The characters analysed were the three essential for yield, namely, bean number, wet cacao weight, and the mean weight of a single bean calculated from the first two measurements. The statistics presented are Mean, Standard Deviation, and Coefficient of Variability expressed as a percentage of the Mean.

Table 17.

Bean Number. Summary of Statistics. Clones.

Clone.	Mean.	St. Devn.	Coeff. of Var.
1	31.50	5.745	18.24
2	30.00	5.765	19.22
3	31.08	6.295	20.25
4	39.28	5.679	14.20
5	38.14	5.273	13.82
6	43.63	4.422	10.14
7	33.72	3.772	11.19
8	39.41	6.790	17.23
9	36.76	4.504	12.26
10	30.84	4.971	16.12
11	31.76	6.433	20.25
12	37.58	8.113	21.59
13	25.07	6.223	24.82
14	38.85	4.827	12.42
15	35.96	4.633	12.88
16	34.75	5.381	15.49
17	32.58	4.243	13.02
18	29.33	4.786	16.32
19	30.00	4.517	15.06
20	31.17	6.419	20.60
21	32.24	4.942	15.33
22	29.27	6.519	22.27
23	28.84	5.642	19.56
24	35.93	5.760	16.03
Average ..	..	..	16.60

Table 18.

Bean Number. Summary of Statistics. Trees.

Tree.	Mean.	St. Devn.	Coeff. of Var.
1	36.46	8.22	22.54
2	31.91	4.22	13.22
3	25.94	7.85	30.26
4	35.00	4.55	13.00
5	33.00	5.20	15.76
6	34.31	5.00	14.57
7	40.68	5.61	13.79
8	33.00	6.20	18.78
9	31.86	5.92	18.58
10	40.67	5.41	13.30
11	35.82	4.46	12.45
12	34.42	7.50	21.79
13	33.43	6.14	18.37
14	26.01	6.50	24.99
15	33.93	3.22	9.48
16	31.37	6.04	19.26
17	35.00	6.18	17.66
18	33.78	4.46	13.20
19	34.29	5.71	16.65
20	33.57	3.80	11.32
	33.72	5.61	16.95

The three yield characters will be discussed in turn.

Bean Number.—Table 17 presents the statistics for bean number in the twenty-four clones. The clonal means vary from 25 beans per pod to 43, showing that some clones certainly have significantly more beans than others, a character

in keeping with seedling trees. The Coefficient of Variability varies from 10.14 to 24.82. The average coefficient of the 24 clones is 16.60. Similar statistics for twenty individual high bearing trees are presented in Table 18. The figures are strikingly similar to those for the clones. Table 19 picks out the extreme values to illustrate this point more clearly in the case of coefficients of variability.

Table 19.

Bean Number. Coefficients of Variability.

		Minimum.	Average.	Maximum.
Clone	..	10.14	16.596	24.28
Tree	..	9.48	16.950	30.26

For the twenty *trees* the range is wider than for the *clones*, both above and below the mean, although the figures are not significantly different. The fact arises however that for all practical purposes, *a clone in the field is no more variable with respect to bean number than the individual tree.*

Wet Cacao.—Similar statistics for this character are presented in Tables 20, 21 and 22. Again the clonal and tree statistics are very similar. The range in both cases is approximately the same but the clonal extreme values (Table 22) are in each case lower than the corresponding tree values. As with bean number this proves that the clone as a unit is no more variable than the individual tree.

Table 20.

Weight of Wet Cacao. Summary of Statistics. Clones.

Clone.	Mean.	St. Devn.	Coeff. of Var.
1	92.44	18.759	20.29
2	106.76	23.541	22.05
3	128.75	28.950	22.48
4	140.95	27.391	19.43
5	122.44	22.295	18.21
6	119.92	20.166	16.82
7	117.44	17.681	15.06
8	133.82	25.974	19.41
9	125.00	23.862	19.09
10	94.09	17.074	18.15
11	126.73	26.393	20.83
12	172.67	34.536	20.00
13	95.72	25.042	26.16
14	109.32	18.818	17.21
15	116.17	16.754	14.44
16	122.77	24.996	20.36
17	98.30	17.188	17.49
18	116.26	18.958	16.31
19	101.09	19.167	18.96
20	128.01	28.061	21.92
21	98.11	21.000	21.40
22	76.83	20.406	26.56
23	96.92	18.677	19.27
24	128.93	22.304	17.30
Average ..	..	..	19.550

Table 21.

Weight of Wet Cacao. Summary of Statistics. Trees.

Tree.	Mean.	St. Devn.	Coeff. of Var.
1	99.17	24.10	24.30
2	104.99	21.49	20.47
3	112.42	31.54	28.06
4	110.40	24.12	21.85
5	105.24	22.88	21.74
6	119.14	22.49	18.88
7	122.95	31.53	25.64
8	91.77	18.86	20.55
9	87.94	24.63	28.01
10	125.00	31.01	24.81
11	112.12	21.00	18.73
12	49.59	12.00	24.20
13	103.15	22.02	21.35
14	80.30	21.05	26.21
15	79.75	17.93	22.48
16	107.18	26.65	24.86
17	115.00	23.26	20.23
18	91.12	15.36	16.85
19	130.12	24.35	18.71
20	130.43	23.41	17.95
	103.89	22.98	22.35

Table 22.

Wet Cacao. Coefficients of Variability.

		Minimum.	Average.	Maximum.
Clone	..	14.44	19.550	26.56
Tree	..	16.85	22.350	28.06

Table 23.

Bean Weight. Summary of Statistics. Clones.

Clone.	Mean.	St. Devn.	Coeff. of Var.
1	2.856	0.355	12.42
2	3.500	0.573	16.37
3	4.055	0.438	10.80
4	3.500	0.466	13.32
5	3.135	0.429	13.69
6	2.697	0.367	13.59
7	3.423	0.412	12.03
8	3.297	0.512	15.51
9	3.319	0.521	15.69
10	2.847	0.410	14.39
11	3.937	0.567	14.41
12	4.500	0.523	11.62
13	3.724	0.691	18.55
14	2.763	0.403	14.59
15	3.157	0.399	12.65
16	3.447	0.527	15.28
17	2.946	0.503	17.08
18	3.876	0.582	15.02
19	3.262	0.436	13.37
20	4.076	0.551	13.51
21	2.950	0.444	15.07
22	2.548	0.417	16.36
23	3.287	0.414	12.60
24	3.528	0.486	13.77
Average	..	..	14.237

Table 24.

Bean Weight. Summary of Statistics. Trees.

Tree.	Mean.	St. Devn.	Coeff. of Var.
1	2.72	0.473	17.39
2	3.23	0.499	15.45
3	4.25	0.800	18.82
4	3.17	0.540	17.03
5	3.24	0.498	15.37
6	3.50	0.600	17.14
7	3.00	0.593	19.77
8	2.74	0.476	17.37
9	2.68	0.516	19.25
10	2.83	0.535	18.90
11	3.11	0.51	16.40
12	1.37	0.23	16.79
13	3.12	0.49	15.71
14	3.06	0.69	22.55
15	2.37	0.45	18.99
16	3.47	0.55	15.85
17	3.26	0.41	12.58
18	2.66	0.47	17.67
19	3.75	0.52	13.87
20	3.90	0.60	15.38
	3.07	0.301	17.12

Bean Weight.—The statistics for bean weight are presented in Tables 23, 24 and 25. Again the same conclusions may be drawn. In extreme values the clone is always less variable than the tree and even the range of variability is less (Table 25).

Table 25.

Bean Weight. Coefficients of Variability.

	Minimum.	Average.	Maximum.
Clone ..	10.80	14.237	18.55
Tree ..	12.58	17.120	22.55

Summary of Pod Value Analysis.—Both clones and trees vary widely in pod value statistics but the range of each is almost identical. This means that the budded clone in the field may be regarded as an individual high yielding tree and for practical purposes the variability introduced by the non-uniform rootstock does not show up because the range of pod value on one tree is sufficiently large to mask it. However there is a detectable effect of rootstock without doubt, which will be discussed in the next section.

The Influence of Rootstock.

The large variance between trees of a clone as regards number of pods produced per annum suggests that rootstock has its influence on the bearing of a budded tree. Actually in the field it is obvious that there is some such effect, for the number of dwarfed and unproductive trees amounts to two or three in each clone of ten. In the case of three clones there were sufficient trees which gave a total of more than twenty pods each, to warrant

an analysis of the tree to tree variability within the clone. In this way the differential effect of rootstock on uniform scion material may be demonstrated.

1. The Case of Clone 1.

There were five trees of clone 1 which gave more than twenty pods from the total of the three pickings. The statistics of Bean Number and Weight for twenty of these at random from each tree have been treated by the Analysis of Variance method for significant differences. Table 26 shows that for Bean Number the variance between trees is less than within trees, demonstrating that among these five trees the different root systems appear to have no effect on bean number. However for Bean Weight (Table 27) the variance between trees is significantly greater than that within trees, which suggests that some root-systems tend to produce larger beans than others from the same scion material.

Table 26.

Clone 1. Bean Number. Analysis of Variance.

Due to	D.F.	Sum of Squares.	Mean Square.
Between Trees ..	4	82.1	20.52
Within Trees ..	95	2,458.4	25.88
Total ..	99	2,540.5	

Table 27.

Clone 1. Bean Weight. Analysis of Variance.

Due to	D.F.	Sum of Squares.	Mean Square.
Between Trees ..	4	100	25.0
Within Trees ..	95	1,084	11.4
Total ..	99	1,184	

2. The Case of Clone 2.

Again there were five trees available for analysis. In this case however there appears to be an effect of root-system on bean number for the variance between trees is appreciably greater than that within trees (Table 28). The effect on Bean Weight is much more pronounced than in the case of the first clone (Table 29).

Table 28.

Clone 2. Bean Number. Analysis of Variance.

Due to	D.F.	Sum of Squares.	Mean Square.
Between Trees ..	4	225.7	56.4
Within Trees ..	95	2,425.3	25.5
Total ..	99	2,651.0	

Table 29.

Clone 2. Bean Weight.—Analysis of Variance.

Due to	D.F.	Sum of Squares.	Mean Square.
Between Trees ..	4	762.3	190.6
Within Trees ..	95	2,049.3	21.6
Total ..	99	2,811.6	

3. *The Case of Clone 24.*

Here again from an analysis of seven trees there is no detectable influence of root-system on bean number but the bean weight from tree to tree differs very significantly. (Tables 30 and 31).

Table 30.

Clone 24. Bean Number.—Analysis of Variance.

Due to	D.F.	Sum of Squares.	Mean Square.
Between Trees ..	6	219.4	36.6
Within Trees ..	133	4,458.9	33.5
Total ..	139	4,678.3	

Table 31.

Clone 24. Bean Weight.—Analysis of Variance.

Due to	D.F.	Sum of Squares.	Mean Square.
Between Trees ..	6	507.7	84.6
Within Trees ..	133	3,065.0	23.0
Total ..	139	3,572.7	

Thus in one case of three it appears that the root-system has some modifying influence on the average number of beans per pod produced by the tree while in all three cases there is undoubtedly a very pronounced effect on the average size of the

bean (as shown by its weight). In order to complete the picture, additional statistics are presented in Table 32 for Clone 24 to show that heavy individual beans do not necessarily go with a small average number per pod.

Table 32.

Summary of Performance of Seven Trees. Clone 24.

No. Beans per pod.	Wet Cacao per pod.	Single bean.	4 Years ann. yld.
35	119—gms.	3.4—	55—
36	135 „	3.75	58—
35	126 „	3.6	42—
38	120— „	3.2—	87
37	130 „	3.5	84
36	121— „	3.4—	65
34	127 „	3.7	80

There is quite an appreciable positive correlation between the mean weight of wet cacao per pod and the mean weight of a single bean. This suggests that the whole effect of root-system is one of nourishment. The mean annual yield in pods, calculated over four consecutive years also bears little relation to the pod statistics. Tree 4 which is the best bearer, has the smallest beans but Tree 5, which in bearing capacity is practically the same, produces quite large beans and the second highest mean weight of Wet Cacao per pod.

General Summary.

1. The variability in bearing capacity among budded clones of cacao is definitely less than among seedling trees from the same parents and under the same conditions.

2. The variable root-system probably has a marked influence on the bearing capacity of budded clones.

3. There is evidence that the root-system can influence the size of the bean produced by the scion and possibly also the number of beans per pod. The effect on bean size is marked, and opens up an extensive field of further research, whilst the possible effect on bean number needs further investigation.

FURTHER NOTES ON CRITERIA OF SELECTION IN CACAO.

BY E. E. CHEESMAN AND F. J. POUND.

CERTAIN methods and criteria for selecting desirable types of cacao trees from the Trinitario population were discussed in the Second Annual Report, and from certain friendly and welcomed criticisms which have reached us we judge that some amplification of the bare outline there presented is desirable. The subject is of grave importance, since methods adopted now are likely to have an appreciable effect on the cacao crop of twenty years ahead, and consequently it can scarcely receive too much attention.

One question raised concerns the applicability of methods evolved in Trinidad to the cacao crops of other countries. Our view is that we are dealing in Trinidad with one of the most complex cacao populations in the world, and almost certainly with the most complex in the British Empire. That view may be open to question, but it has never yet been seriously challenged. Consequently we hold that, so far as problems of genetic constitution are concerned, we may meet difficulties not arising in other countries, but

difficulties arising elsewhere are not likely to be unparalleled here. It follows that methods appropriate to the Trinidad crop may be simplified elsewhere without loss, but are unlikely to need elaboration. It is indeed for this reason, weighed from the beginning of the programme, that the Trinidad crop was chosen for detailed genetic analysis.

To be more specific, the cacao-growing countries of the Empire concerned with these researches are Gold Coast, Nigeria, Trinidad, Grenada and Ceylon. These represent four distinct cacao populations, since the first two countries have substantially the same type of tree. The Grenada population is a Trinitario of lower average quality than that of Trinidad. In other words its range of variability is curtailed at the upper, or Criollo end of the complex, but it is otherwise similar. The Ceylon population on the other hand is known to consist of a substantial basis of Venezuelan Criollo, mixed to some extent with later introductions from Trinidad, and consequently is a Trinitario of higher average quality than that of Trinidad, with a greater proportion of its members in the upper, or Criollo end of the complex, but otherwise similar. In neither case is there any ground for supposing that methods appropriate in Trinidad would be inappropriate locally. No doubt each population is suited to its own climate and conditions, and consequently as we pointed out before a lower actual *standard* of selection may be necessary in the one case, whilst a higher one may be possible in the other, but the actual standard to be aimed at must in any case be decided by each country for itself and does not affect the method used to attain it.

It is the West African cacao population, by far the most important in size, which alone differs radically from that of Trinidad, and this by general consent is very much more restricted in its range of variability than any of the other three. The question does therefore legitimately arise, whether there is within that population similar scope for crop improvement by utilisation of existing variation, and we have been at some pains to examine the literature with that question in mind. We find that wherever individual tree records have been kept, as for example at Asuansi (4) and Aburi (5), sufficient variation in yield per tree has been noted to justify selection and further investigation of progenies. The Aburi records are remarkable in one respect. Of 238 trees which survived throughout 13 years of observation, only 4 averaged less than 26 pods per annum and only 32 less than 56 per annum; the mode falls in the 101-115 class, and the mean yield over the whole field was 95 pods per tree per annum. These trees were 22 to 24 years old at the commencement of observations and 35 to 37 at the end of the period reported, and the field is noted as exceptionally good by local standards. For a Trinidad field, such a low proportion of shy bearers would be highly exceptional, and the figures suggest that at Aburi one of the complicating factors in the Trinidad crop is absent or unimportant, namely

self-incompatibility. If any substantial proportion of self-incompatible trees are present in this field, the conditions for natural crossing must be particularly favourable. On the other hand, though trees at Asuansi yielded an average of about 40 pods between the ages of 9 and 16 years, there was a mean percentage of 10.8 giving no pods at all, and 33.7 per cent. giving less than 21. The difference may be ascribable to age and environment, or in this case self incompatible trees may be present, and the question remains open for experiment.

Another possible consequence of the restricted origin of West African cacaos is a narrow range of variability in pod value. Calabacillo types are recorded as occurring on the Gold Coast (6) and although they are understood to be infrequent, they are likely to have crossed with the prevailing Amelonado to some extent, or still more probably they are themselves segregates from the latter. Hence it does not seem *a priori* probable that variation in pod value is entirely negligible in this population. The published records support a belief that such variation exists and may be utilised in selection. For example, at Kpeve in 1932 (7) a 20-acre field planted at 13 by 13 feet yielded at the rate of 629 lb. dry cacao per acre, or 3.72 lb. per tree. Yields per tree ranged from 17.4 lb. downwards, and 11 individuals produced more than 10 lb. each. Among the 22 highest yielders, the pod value ranged from 11.7 to 22.7 pods per lb. dry cacao, and since all these trees were presumably well-nourished there is a strong suggestion that much of that variation in pod value was due to genetic causes. Incidentally the best yielding tree required more than 18 pods to the pound of cured cacao, and unless there were fewer than 30 beans per pod must have produced beans 540 or more to the pound. It should certainly be possible to improve on this size without sacrifice of hardiness or yield. The range in pod value shown in this single case is as expected narrower than the Trinitario range, but it is still appreciable, and suggests that our selection methods, with adjusted standards, would be applicable. Conclusions need not, however, be forced from a single case. If it can be statistically shown that pod value and bean size are negligible in economic selection from West African cacao, simplification of the procedure appropriate to the Trinitario complex will be indicated. Pending such statistical demonstration, our suggestions appear to hold good.

Another question raised concerns the influence of environment, and this is of the utmost importance. Our own figures (in "The Genetic Constitution of the Cacao Crop") support similar data from the Gold Coast and elsewhere in showing the profound effects of season on yield and all its component factors. It would be unreasonable to expect the effects of soil variation and topographical factors to be any less marked, though they are less easy to assess. The question in plain language is "How can one assure that selection isolates the best genetic types, and not merely trees which are good simply because they are in a

good spot in the field?" That problem is one of the fundamentals of plant breeding, and there is no entirely satisfactory answer, but there are several ways in which the risk of confusion between genetic factors and physiological factors can be minimized. With perennial crops the usual procedure is to take into account the yield of trees in the immediate neighbourhood of the individual selected. Soil variation is usually such that a good "pocket" includes several trees, and hence a good tree surrounded by others above the average is always suspect, whereas in the case of an outstanding good tree surrounded by average or poor ones the odds are on the superiority being genetic. In our own selection we have not thought it advisable to attempt any statistical estimate of this positional correlation, but we have by no means neglected it. With a large population to survey, and standards set to exclude 98 per cent. of it, most of the comparison with neighbouring trees must of necessity be done by eye, and in practice we rarely find doubtful cases. Our selections are very thinly scattered in the fields, and as a rule the individual is bearing at least four or five times the crop of any neighbouring tree.

In a more uniform initial population greater precautions would be necessary, counterbalanced by the fact that a smaller population need be surveyed, and a larger percentage would pass the selection standards. This is not a case of difficulties arising elsewhere which do not occur in Trinidad, but rather another example of simplification possible in a less complex population. We are selecting initially 1,000 trees to be reduced to 100 before detailed comparisons begin. Under more favourable conditions the 100 might be selected in the first stage, and detailed comparisons applied in the second stage. In either case the final test of the selections is the detailed comparison of the progeny, and it is only then that genetic and environmental factors can be clearly separated.

A third point calling for comment is raised by the partial self-sterility which has now been shown to be a definite factor in the Trinidad crop. The establishment by vegetative propagation of a self-incompatible clone would lead to disaster of which we have ample warning in the case of certain other crops, but fortunately there appears to be little risk of such a contingency. All selections will naturally be tested, but so far it appears that trees passing the standard are automatically ensured to be either completely or sufficiently self-compatible. The heavy bearers selected in the past by the Trinidad Department of Agriculture are probably all self-compatible, and it would in fact appear that all the chances are against a self-incompatible tree bearing sufficiently heavily to be selected at all, so that in practical work compatibility can probably be largely ignored without danger. In cases where seedling progenies are to be grown, however, the matter may require much more attention. It is quite possible that self-compatible trees, heterozygous for compatibility factors, may segregate some self-incompatible progeny. Purely as hypothesis we advance the

suggestion that such segregation may partly account for the disappointing results from some seedling progenies in the past. The possibility introduces no new complications into the improvement of cacao, but it does re-emphasise the principle that the final test of the selection is the behaviour of its progeny.

Finally some notes may be given on the concept of *productive efficiency*, which was touched upon very lightly in the last Report. The convenience of the single tree as a unit in the study of cacao yields must never be allowed to obscure the facts that yield per acre is far more important than yield per tree, and that quality has a place, if secondary, in determining the profitability of the tree and the crop. Remembering that profit per acre is the product of yield and selling price, minus costs of production, we find much beside yield per tree to be taken into account in selection.

The size of selected trees is particularly important, and depends upon both age and vigour. Particularly in cacao heterogeneous in age, like most Trinidad plantations, the heavy bearers are frequently found to be overtopping several of their neighbours and occupying much more than their fair proportion of soil room. We have therefore adopted in all cases a rough correction for size, obtained by estimating as closely as possible the area effectively occupied and calculating therefrom the theoretical yield from an acre of trees identical in size and genotype. The use of this method may be illustrated by reference to six recorded trees which on their average yield in pods over 10 years must be classified as heavy bearers. They are scattered individuals in fields planted originally at 14 by 14 ft., and in every case are occupying more than their fair share of space.

Table 33.
Size of Tree and Cacao Yields.

	Pods per an. Tree. (av. of 10 years).	Size of tree (ground area occupied).	Pods to 1 lb. drycacao (approx- imate).	Dry cacao per tree (calcu- lated).	Potential yield per acre.
A	230	24ft. x 24 ft.	11.5	20.0 lb.	13.4 cwt.
B	194	20 x 20	10	19.4 "	18.9 "
C	240	24 x 24	10	24.0 "	16.1 "
D	283	24 x 24	10	28.3 "	18.9 "
E	233	24 x 24	12	19.4 "	13.0 "
F	232	24 x 20	9	25.8 "	20.9 "

It will be observed that only one of the six yields at a rate above a ton per acre, and that only just above, whilst the pod value shows the beans to be below our first grade. As noted below, 2,114 lb. per acre (7 lb. per tree at 12 by 12 ft. spacing) is our lowest limit for selection even in the highest quality class, and trees requiring 10 pods to the pound must give a calculated yield of over 3,000 lb. per acre to pass our standards. Thus none of these heavy bearers reaches a standard of efficiency which our selections prove to be attainable.

It is of course impossible to make an accurate correction for size. A tree occupying 17 by 17 ft. is held by our procedure to be as efficient as a tree with half the yield occupying only 12 by 12 ft. but we do not claim that the two are by any means of equal status. The one has greater vigour, which might commend it under certain circumstances, the other was possibly earlier in coming into bearing and may be appreciably cheaper to pick. Final comparisons of efficiency in these and other respects must be made on the progeny. Meanwhile for practical selection, and rough as it is, the correction is felt to be better than none.

Among trees which produce equal quantities of cacao per unit of land occupied, those which produce it in relatively few large pods are more efficient than those bearing a larger number of smaller pods. Their greater efficiency operates in two ways. It decreases costs of picking and breaking and it tends to increase the value of the product by virtue of the association between large pods and large beans. Similarly between pods containing equal weights of cacao, those with the fewest and largest beans are the most efficient, other factors being equal, because they again yield the better quality product. In Trinitario cacao a further advantage is given by round beans over flat beans of the same weight, because roundness is an expression of Criollo genes and tends to be associated with a light break and high quality.

A type efficient in one environment may be very inefficient in another. The conclusions reached by Auchinleck and Knowles (8) from comparison of four varieties on six stations on the Gold Coast illustrate this point so well that they may be quoted verbatim:

It will be seen that the Criollo type has given uniformly poor results at all stations and must therefore be considered unsuited to the condition of soil, climate and treatment which obtain on the Gold Coast.

At Aburi, Kibi and Peki, the results of Amelonado are far ahead of either Ocumare or Cundeamor, at Asuansi and Kumasi the results with Ocumare and Cundeamor closely approach those of Amelonado while at Wiawso the yields of the last two are superior to the yield from Amelonado.

Aburi differs from all other stations in its high elevation.

The stations Kibi and Peki cannot be considered to be very good cacao land. Asuansi and Kumasi and Wiawso are fair. These results suggest that Cundeamor and Ocumare are likely to do well only in the better land, where the results will approach and may beat those of Amelonado but the latter will be the most successful on the poorer areas and in the higher elevation is therefore the one to be generally used.

When factors other than yield are taken into consideration the same principle holds. In the older fine cacao producing countries Criollo types have steadily lost ground to more efficient types from the upper end of the Forastero complex, yet even pure Criollo continues to be an efficient

producer in a few specially favoured localities, where its yield is sufficient, coupled with its high quality premium, to make it profitable in its own small market. In these same fine cacao countries, where the industry depends for its very existence on a moderate quality premium, it is doubtful whether any yield practically obtainable could make the lower Amelonado types efficient. Thus between countries totally different genotypes may be necessary for success in cacao cultivation, and even within one country there is much to be done in the fitting of different genotypes to different localities before maximum efficiency can be secured all round.

For these reasons, as noted in the last Report, our selection programme provides for the establishment of a range of types each likely to be efficient in its own appropriate environment. The parents are being located on alluvial soils, sands and clays, good and bad; on exposed sites and well shaded sites; from fields well drained and poorly drained. The aim is less to find the most efficient trees in all Trinidad, which would be an academic ideal, than to establish standards of efficiency represented by the best we can find in a necessarily limited search.

The selection limit in pounds of dry cacao per tree (calculated at 12 by 12 ft. spacing) ranges from 7 (corresponding roughly to 1 ton per acre) upwards and varies with the bean weight. A tree with beans averaging 4 grams (wet) or heavier, passes on a yield of 7 lb. or more, and many selected trees have much heavier beans than this. A tree with beans averaging less than 4 grams but more than 3.5 grams passes on a yield of 10 lb. Among trees with beans below 3.5 grams we have not finally fixed the selection limit, but we have located several bearing at a rate above 3,000 lb. per acre. The lowest limit of pod size is fixed by the present Trinidad average of 12 to the pound, and consequently no trees with very small beans will be included at all.

There will finally be several individuals in each class, and broadly it is hoped that one or other of those with 4 gram and 3.5 gram beans will suit all localities in the fine cacao countries where cacao is likely to remain a profitable crop, whilst the heavier yielders of rather lower quality cacao may be of particular interest elsewhere.

In another part of this Report appear the first descriptions of selected trees, and the series will be continued in subsequent years.

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THE PROGRESS OF SELECTION, 1933.

BY F. J. POUND.

AMONG the trees which pass our first selection standards of pod value and bean size there are a few which have had their pod numbers recorded for some years by the Trinidad Department of Agriculture and a few others which have, during the last two years, been known to carry pods in excess of the lower limit necessary for selection on yield in the second stage. These have been given I. C. S. (Imperial College Selection) numbers and will be included in the comparative tests to be laid down on the best 100 trees found. The year 1933 has been unfavourable to the cacao tree in Trinidad and most trees during the earlier months of the 1933-34 crop bore very few pods. In some cases even the I. C. S. trees which had borne well for two years previously did not conquer the adverse conditions. Setting was not at fault for time after time crops were set and lost. With the advent of better weather conditions a fair crop is setting again in many places but descriptions of those selected trees which failed to hold a main crop are being withheld for the present. Even the trees described in this paper will be watched carefully for several years yet to test whether they are consistently good yielders.

In addition to these which are scion selections nine trees have been selected for first trial as clonal stocks. These trees are all of exceptional vigour and have been known to bear a crop of several hundred pods consistently for several years. They do not give a high quality produce, generally the reverse is the case, but besides cropping and vegetative vigour these trees appear to be highly resistant to the common maladies which attack the average cacao tree. Calabacillo types are known and will also be tested as stocks when space and time permit. Those with which we are familiar have nothing to commend them either for hardiness or vigour and they have been omitted in favour of more vigorous Forastero types.

Before proceeding to the descriptions it must be borne in mind that the types described occur as isolated trees in the field. They stand out from their neighbours on account of yield efficiency, which means that they are more genetically suited to the particular environment in which they occur. Grown in competition with equally efficient trees under present haphazard methods of culture they may not appear so desirable but the capacity for high yield is nevertheless in the tree and is capable of realisation. For this reason the actual yield of the tree as it stands has been expressed as a 'yield per acre', after taking into consideration the probable feeding area which the tree occupies.

I.C.S. 1.—(Plate I.)

This is a mature tree growing on a light alluvial soil to which additions of pen manure have been made recently. Before the applications of pen manure the tree bore a total of 1,059 pods over a 10-year period which is an average of 106 per

annum. The site is well drained and not subject to flooding. The tree is healthy and is occupying its full 14 by 14 ft. space. The pods are long and oval measuring on an average about 24 by 10 cms. The shell is of medium thickness and is more than partially pigmented on a white base. There is just a suspicion of a neck constriction to the pod.

A sample of 30 pods taken altogether at 3 periods gave a mean bean number of 42 and a weight of wet cacao of 180 gms. This means that the individual beans are well above the selection standard for bean size. On the assumption that $6\frac{1}{2}$ pods give one pound of cured beans the tree is yielding 16 lbs. of Superior beans per annum at the rate of 32 cwts. per acre.

I.C.S. 2.—(Plate II.)

This tree is a supply of about 12 years of age growing on a light alluvial soil close to a river bank and is subject to frequent floods in the wet season. Although it has never received more than ordinary estate treatment it is remarkably large for its age and occupies a 12 by 12 ft. space to the full. During the last two crop seasons it has produced approximately 60 pods each year. During the present crop it is producing many more than 60. The pods are not large, measuring but 15 or 16 cms. in length and 8 to 9 cms. in diameter. The shell is exceedingly thin measuring 0.8 cm. only and is slightly pigmented on a green base. The surface is just warty and there is a slight stalk end constriction.

From pods taken at various times the mean bean number appears to be 38 and the weight of wet cacao 170 gms. The individual beans are more than 'Superior' in size and the tree must be producing 9 lbs. of cured beans per annum at the rate of 25 cwts. per acre.

I.C.S. 3.

This is a mature tree growing in a very gravelly soil on one of the recognised poorer sites of the estate in question. It stands out from its neighbours of the same age on account of its vigour and although planted at 12 by 12 ft. spacing it now occupies an approximate ground area of 16 by 16 ft. and is a tall tree with a crown of foliage at the top. During the two years that it has been under observation the tree has produced a total of 160 pods. They are rather short oval in type measuring about 15.5 by 9 cms. The shell is of medium thickness and is partially pigmented on a white base. The surface is smooth and the pod has neither prolonged apex nor neck constriction.

A sample of 30 pods showed the mean number of beans per pod to be 42 and the wet cacao 185 gms. The beans equal those of I. C. S. 2 in size and the tree must be producing at the rate of 25 cwts. cured beans per acre.

I.C.S. 4.

At one time this tree was rather larger than it is at present but the remaining portion is bearing well. It is situated on an elevated gravel plateau which is never subject to flooding. The soil appears to be of average fertility. During the period 1914-23 inclusive it produced a total of 1,800 pods, which is equivalent to an annual yield of 180. At that period it was recognised as a promising tree and was used as a scion selection. It bears pods in clusters all the way up the trunk. These pods measure 17 by 9.5 cms. The shell is of average thickness and is completely unpigmented (on a white base). There is rather a decided point but no neck constriction.

The bean number averages 36 per pod and the wet cacao 170 gms. Each individual bean thus weighs 4.7 gms. on an average which is far above the selection point for bean size. Assuming that during the period of pod records the tree was occupying a space of 20 by 20 ft. (although planted at 14 by 14 ft.) its yield must have been at least 25 lb. of cured beans per annum at the rate of 27 cwts. per acre.

I.C.S. 5.

This tree occurs in a sandy alluvial soil with a fair proportion of gravel. It is not an old tree and those around it are noticeably poor both in yield and quality. It receives no special treatment other than general estate cultivation. The space occupied is about 14 by 14 ft. It was discovered about four years ago and observed to be a good bearer. During the two years under observation it has produced approximately 70 pods per annum. These pods are very large and full to both ends, measuring about 23 by 10 cms. The shell is not thick and is partially pigmented on a white base. The surface is slightly warty.

From pod samples taken at various times the mean bean number is found to be 44 and the wet cacao 190 gms. The individual beans are large and round. Assuming that 6 pods on an average produce 1 lb. of cured beans the tree is yielding about 11 lb. of very superior beans per annum at the rate of 24 cwts. per acre.

I.C.S. 6.

Situated in a sandy soil which is not subject to flooding this tree was the more vigorous of the two originally growing at the picket. Consequently it is ill-shaped and not taking advantage of its planting space, although it occupies a full 12 by 12 ft. area. It has only been recorded for one year during which it matured 54 pods but during this present crop it will produce many more. The pods are not long, measuring about 17 cms. by 9. The shell is medium to thin, warty and green with no red pigment. There is no bottle neck or prolonged apex.

The mean bean number is 43 per pod and the wet cacao weight 210 gms. Each individual bean weighs nearly five grams. Its yield is calculated to be approximately 10 lb. of very large beans per annum at the rate of 25 cwts. per acre.

I.C.S. 8.

It is difficult to decide whether this tree is good entirely on account of genetic constitution for although it is an F_2 selected seedling progeny it is growing on a river bank nicely sheltered by an immortal shade tree. Frequently the soil is flooded especially in the rainy season and no other trees around are exceptionally efficient. The pod is rather large, measuring 21.5 by 10.5 cms. The shell is thin, measuring but 1.2 cms. It is unpigmented, white based and slightly warty with a slight neck constriction. The owner states the tree bears 200 pods per annum. In March, 1933, it was holding 100 pods and there was evidence of many having been picked just previously. The ground area occupied was about 16 by 16 ft.

The mean bean number amounts to 44 per pod and the wet cacao 208 gms. The individual beans are thus exceptionally large. Although the annual yield cannot yet be definitely calculated it must be at the rate of at least 30 cwts. per acre.

I.C.S. 18.

This is a tree of about 20 years of age planted as a supply in an old field with a fairly heavy soil. The tree itself is situated on a raised plateau and never suffers flooding. It occupies a space of approximately 14 by 14 ft. and is low growing. It has yielded 50 pods during each of the last two seasons. In the present crop it produced 48 pods up to January 1934 and is still setting fruit. The pods are very large, in type like I.C.S. 5, long oval and full to both ends without bottle neck or prolonged apex. They measure about 22 by 11 cms. The shell is thin, rather more than partially pigmented on a white base and only slightly warty.

The mean bean number equals 44 per pod and the wet cacao 184 gms. For its size the tree is yielding well at the rate of about 20 cwts. per acre.

I.C.S. 19.

This tree grows in the same line as the previous example but about 100 yards away. It is quite probable that it originated from the same parent as both are of similar age and size. This pod differs in being rather thinner, rather more warty and more completely pigmented with a slight neck constriction. In habit it is low growing, spreading over an area of 14 by 14 ft. For two years it has produced about 50 pods per annum of mean dimensions 19 by 9 cms.

The beans average 38 per pod and the wet cacao 170 gms. The individual beans thus weigh 4.5 gms. wet. Although the yield is slightly less than 1 ton per acre there is no doubt of the efficiency of the tree.

I.C.S. 21.

This is a mature tree, 25 years of age, of very vigorous and healthy appearance, standing on the brow of a small hill. The soil is clayey and considered to be rather poor. The interest in the tree lies in its probable hardiness from drought for during the 1926 drought this tree and a few of

its neighbours were among those which survived; and curiously they have unpigmented pods whilst most of the survivors possessed very dark red pods. The tree is not of Trinidad origin and shows relics of Nicaraguan or *Theobroma pentagona* ancestry in the pod markings. There is no bottle neck but a decided point at the apex. The pods measure about 19 by 9 cms. and the shell is thin. The individual beans are large and round often with a light break.

The mean bean number is 32 which is suggestive of Criollo. The wet cacao weight averages 150 gms. per pod. Thus although $7\frac{1}{2}$ pods are required to produce 1 lb. of cured beans the individual beans are very fine. During the last two years the tree has matured more than 100 pods and occupies a space of 12 by 12 ft. Its yield must be in the region of 20 cwts. per acre.

I.C.S. 22.

This tree also originated outside of Trinidad. It now grows on a very steep slope, and is a vigorous tree spanning an area of 18 by 18 ft. The pods are large and plump and during the crop 1932-33 it produced 90 to 100 pods and in the present crop up to December, 1933, already 79 pods had been reaped. They measure on an average 18.5 by 11.5 cms. with a shell of medium thickness. The surface is slightly warty, partially pigmented on a white base and without neck constriction. Some of the beans are large and angular with a very light break.

The mean bean number is 30 which is low for Forastero but the wet cacao averages 175 gms. per pod. This means that the individual beans often weigh more than 6 gms. each. On the basis of 90 pods per annum the tree is producing 14 lb. of exceptionally fine beans at the rate of 20 cwts. per acre.

I.C.S. 29.

This tree grows in a gravel soil which is well drained and rarely flooded. Planted at 14 by 14 ft. it occupies a little more than its allotted unit. The pods are deceptive, measuring only 16 by 9 cms. with slightly less than medium shell thickness and no red pigment. They are smooth, with a white base and no neck constriction. During 10 years recordings the tree produced a total of 852 pods or 85 per annum.

The beans average 41 per pod and the wet cacao 170 gms. which means less than 7 pods to the pound of cured cacao. On this basis the tree produces 12 lb. of cacao per annum at the rate of 20 cwts. per acre.

I.C.S. 30.

This tree is growing on an alluvial vega of the Northern Range. It is probably quite an old tree but on account of its position near the public road, it has been consistently confined to a ground area of 14 by 14 ft. In 1932-33 when actual records were first taken it produced 79 pods and by the end of December, 1933, there were an additional

51 pods and a number of cherelles. For many years it has been noticed as a high bearer. In type the pods are almost completely pigmented on a green base, measuring about 19 by 9 cms. The shell is of moderate thickness and rather warty.

The beans average 40 per pod and the wet cacao 165 gms. Thus with an annual yield of 80 pods the tree must be producing 11 lb. of superior cacao at the rate of 21 cwts. per acre. From the appearance of cushions on the trunk it is probable that at one time this tree was much more productive.

I.C.S. 31.

On the estate where this tree occurs it has been the practice to allow chupons to grow as renews and the tree now consists of three spindly chupons which altogether do not occupy more than an area of 100 sq. ft. The soil in which it is growing is probably rich but there are large boulders around. The pod is rather thick shelled, very slightly warty, and partially pigmented on a white base. It measures about 18 by 10 cms. and there is no neck constriction. For two years the picket has produced an average of 45 pods per annum, chiefly on the three trunks.

The beans are plump and average 38 to the pod. The wet cacao averages 170 gms. per pod. The yield is thus between 6 and 7 lb. per annum at the rate of 24 cwts. per acre.

I.C.S. 32.

This is another of the drought survivors situated on the same hilltop as I.C.S. 21. In type both are very similar. It is more than likely that they came from the same source in Central America. The pod is rather small measuring only about 18 by 8 cms. The shell is unpigmented, thin and warty. The tree is more vigorous than I.C.S. 21 for although planted at the same time it now spans a space of quite 16 by 16 ft. and yields not less than 100 pods per annum.

The mean bean number is 30 per pod and the wet cacao 150 gms. The individual beans are very plump. On the basis of 7 to 8 pods to the pound of cured cacao the tree is now producing 13 lb. of superior beans at the rate of 22 cwts. per acre.

This concludes the descriptions of 15 types which pass all the selection standards for a first class efficient tree. A few trees occur outside this class, which nevertheless may be very desirable and since they yield at a rate of much more than 1 ton per acre they are being included among the 100 selected trees.

I.C.S. 100.

This tree grows in a gravel-silt soil with very poor overhead shade. It is a large and well-shaped tree occupying a space of 18 by 18 ft. The mean annual yield over 10 years was 191 pods per annum. The pod is not large, measuring but 15 by 9 cms. The shell is moderately thin and green with no pigment. The surface is warty and there is neither neck constriction nor long apex.

The mean bean number per pod is low (about 27 from an average of 20 pods) although externally there is no resemblance to Criollo. The mean wet cacao weight is 128 gms. Thus although 9 pods are needed per pound of cured beans the individual beans are very large. The yield is about 21 lb. per annum at the rate of 3,000 lb. or 27 cwts. per acre.

I.C.S. 99.

This is also a large tree growing in the same field as the previous example. It occupies at least 18 by 18 ft. The pods are round and smooth with a thin shell measuring on the average 15 by 9 cms. They are partially pigmented on a green base. The yield recorded over 10 years amounted to 190 pods per annum.

The mean bean number is 30 per pod and the wet cacao weight 129 gms. Nine pods are usually required to make 1 lb. of cured beans but the beans all pass the superior test for weight although in this case they are a trifle flat. The yield is thus about 21 lb. per annum at the rate of 27 cwts. per acre.

I.C.S. 98.

This tree is growing in a heavy clay soil which is water-logged for the greater part of the year. It occupies a space of about 20 by 20 ft. and has been calculated to bear at least 200 pods per annum. They are very dark red in colour with a smooth surface and a slight bottle neck. The shell is of medium thickness.

The bean number averages 36 per pod and the wet cacao 140 gms. The beans do not pass the first class selection standard but come easily in the second. The greater majority pass into the grade 'Superior'. The yield is about 25 lbs. of cured cacao per annum at the rate of 24 to 25 cwts. per acre.

The first Selections for Trial as Stocks.

In the first 9 selections for stock trees, type has been completely ignored but for the purpose of comparison the pod descriptions are given in the table following. Each of these trees is known individually as phenomenally large and heavy bearing. They have been selected from a variety of soil types because since each one appears so suited to its own spot in the field it may thrive much better in that environment than others. Thus two types (Nos. 1 and 2) have been selected from light sandy or gravel soils which drain easily. Nos. 3, 4 and 5 have been selected because they occur on the famous chocolate soils of the

Montserrat district. No. 6 occurs in very rich soil on a mica schist plateau in the Northern Range. No. 7 has been selected from an alluvial soil which is constantly flooded and always waterlogged during the rainy season. Nos. 8 and 9 occur on very heavy clay soils which are very wet in the wet season but dry out and crack in the dry season.

DESCRIPTION OF POD.

Tree.	Colour.	Surface.
I. C. Stock		
1 Very dark red	..	Smooth—medium furrows
2 Green	..	do. shallow furrows
3 Partial red on green	..	do. medium furrows
4 Partial red on white	..	Slightly warty—shallow furrows
5 Very dark red	..	Slightly warty—medium furrows
6 Partial red on green	do.	do.
7 Partial red on white	do.	do.
8 Green in furrows	..	do. do.
9 Partial red on green	do.	do.

These selections for stocks are not included in the 100 scion selections.

Summary.

Descriptions of 18 types selected as being extremely efficient trees are here presented. These are the first of a total of 100 which will eventually be picked out and added to the list. It is noteworthy that in cacao absolute yield per unit area appears to be independent of type and quality. In crop selection it is usual to find that the poorer quality types give the greatest yield, but with cacao these types, which may be exceedingly high bearing, occupy a large space and their yield per acre is low. This is illustrated by the fact that the best trees available in the 9 to 13 pod to the pound class rarely give a yield exceeding 1 ton per acre (cp. Table 33). For all classes a yield at the rate of 30 cwts. per acre appears to be near the limit which trees or soil can reach in Trinidad under present conditions. The actual yield obtained from the heterogeneous types at present grown is rarely above 6 cwts. per acre which illustrates how costly the poor bearers in the field must be.

Acknowledgment.

The thanks of the writer are due to Mrs. C. Watts for the care which she has taken in preparing in colour Plates I and II which appear in the frontispiece of this Report and for the preparation of many other drawings and paintings not reproduced in this Report.

STUDIES OF FRUITFULNESS IN CACAO.

IV.—An Experiment designed to test the Gross Effects of Applications of Nitrogen, Potassium and Phosphorus on the Cacao Tree.

By F. J. POUND AND J. DE VERTEUIL.

Introduction and Scope of Experiment.

FOR some years past most important data have been collected by the Trinidad Department of Agriculture in the form of natural yield records

(in pods per annum) from a large number of individual trees. Cheesman and Pound (9) recently made use of some of these records to calculate the variability of bearing capacity from

tree to tree with a view to examining the possibilities of conducting manurial experiments on existing cacao. The analyses showed clearly that unless advantage was taken of modern methods of layout and statistical analysis little hope could be entertained of arriving at any satisfactory conclusions. The two factors responsible for much of the variance were found to be age and genetic heterogeneity. Where age could be largely eliminated by using a block of young trees more or less uniform in this respect, a Latin Square layout using not less than 12 to 16 trees per plot stood a fair chance of giving significant results provided the increase in yield due to the treatments applied was of the order of 30 per cent. The failure of some earlier experiments to demonstrate improved yields from application of artificial manures may possibly be due largely to this great variability in bearing capacity.

It was further found that in certain cases when records have been taken for several years prior to the experimental year they can be used to increase the precision of the results of an experiment. Owing to the large effect of seasonal conditions on yield no hard and fast rules can be laid down for the period over which such natural yield records should be taken but for economy it is probably unprofitable to exceed three years. In other cases precision can be greatly increased by combining yields for consecutive years in pairs since for some reason, at present unknown, good and poor crops seem to alternate. Cacao fields of uniform age, in which natural yield figures have been taken for two or three years, are rare, and the Trinidad Department of Agriculture having such a field available on River Estate, decided in collaboration with Cacao Research officers to devote it to a fertilizer experiment, to be planned in accordance with the most recent findings. The advisability of the experiment is clear from several considerations, which will be outlined.

It was reported in the Second Annual Report on Cacao Research that a Genetic Survey of the crop had been completed. It was emphasised as a result of this work that the number of pods borne by a tree is not the only variable factor in yield since the value of the pod and the individual bean are also unexpectedly variable. It was shown that the average number of pods from a tree, required to produce one pound of dry cacao may be as few as six or it may be as many as thirty. Obviously an increase of yield of one pod in the former case is equivalent to an increase of five in the latter.

Further evidence of the effect of culture has been collected indirectly from general estate practices. It is found that in a poor year the beans tend to be much smaller than in a good year and on some estates, unless constant attention is paid to cultivation the beans suffer considerably in size. Thus apart from any effect on pod number the yield of a tree may be increased by virtue of larger beans.

Further light has been thrown on the question of bearing capacity by the discovery of self-incompatibility in cacao trees. The bulk of the really

heavy bearers are undoubtedly self compatible, *i.e.*, they set fruit readily with their own pollen and do not have to wait upon chance visits from flying insects. Many of the poor bearers are not only self-incompatible but are also cross-incompatible with their immediate neighbours. Such trees as these cannot respond to cultural treatment and it is a waste of time and money to manure them.

The poor bearer, the self-incompatible tree and the bearer of small pods must not be allowed to pass into the future cacao field. Even under the present economic conditions there are a number of trees in each field which return a handsome profit to the planter. The best of such trees alone must supply the coming generation. These trees will be self compatible, with a capacity for heavy bearing. In addition they will generally produce large pods and large round beans. In the field at present they show superiority over their neighbours by sheer vigour. This in itself is a desirable characteristic since it shows that the type of selection being made is following natural lines. However, grown in competition with each other they will need to be fed in order that their potentialities for yield may be fully expressed. It is not likely that all of the really desirable types will respond equally to each treatment, but if broad lines for crop improvement can be fixed from experiments with present day heterogeneous cacao, detailed cultural operations, suitable for each type may be evolved when the types are available in sufficient quantities for experiment. Thus although experiments are being made with the immediate aim of improving the yield from present cacao they are directed towards maintaining the efficient types of the future.

Layout and Treatments.

The block available comprises 432 trees at a spacing of 12 by 12 ft. on a flat field, the great majority being of a uniform age of about 30 years. After allowing for guard rows, it is adequate for a 4 by 4 Latin Square, each plot containing 16 trees in two rows of 8. The plots are arranged at right angles to the drains, and are separated sometimes by one and sometimes by two rows of guard trees, the guard rows being selected to include as far as possible the supplies and exceptionally heavy bearing trees which are scattered about the field.

Since there is not room for a Latin Square larger than 4 by 4, and data are required for nitrogen, potassium and phosphorus treatments, a half-plot layout has been adopted. The four whole-plot treatments are:—

1. Control. No manure.
2. Sulphate of Ammonia, 2 lb. per tree.
3. Sulphate of Potash, 2 lb. per tree.
4. Sulphate of Ammonia, 2 lb. plus Sulphate of Potash, 2 lb.

Superimposed on these treatments, half of every plot receives Superphosphate at the rate of 2 lb. per tree.

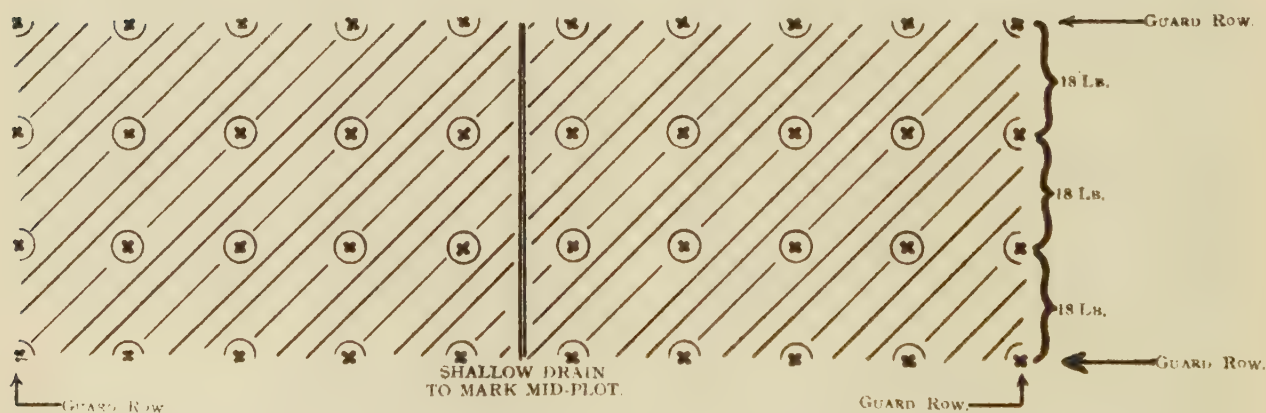
A plan of the experiment is given in text Fig. 3.

TEXT FIGURE 3. PLAN OF MANURIAL EXPERIMENT

-P	A	+P	-P	B	+P	+P	C	-P	-P	D	+P
+P	B	-P	+P	A	-P	-P	D	+P	+P	C	-P
+P	D	-P	-P	C	+P	-P	B	+P	+P	A	-P
-P	C	+P	+P	D	-P	-P	A	+P	+P	B	-P

TREATMENTS {
 A=SULPHATE OF POTASH + SULPHATE OF AMMONIA.
 B=SULPHATE OF POTASH.
 C=SULPHATE OF AMMONIA.
 D=CONTROL.
 +P=SUPERPHOSPHATE ADDED.
 -P=SUPERPHOSPHATE NOT ADDED.

TEXT FIGURE 4. PLAN OF ONE PLOT TO ILLUSTRATE METHOD OF APPLYING MANURES



Application of Treatments.

Manures were applied first in May, 1933, and will be repeated annually in May. The application of Sulphate of Ammonia was duplicated in October to test whether nitrogen has any visible effect on cherelle wilting, as indicated by a preliminary experiment previously reported (10).

On the day previous to the application the whole block was weeded and the leaf debris collected around the base of each tree, leaving the intervening soil fairly clear. For the potash application of 2 lb. per tree, 54 lb. of manure were weighed out and divided equally into 3 parts. The total space manured for each plot was the area shaded in the diagram (text Fig. 4.) Each 18 lb. of manure was spread evenly through the cleared channels indicated. The same procedure was used for the ammonia applications and for the phosphate over the particular half of the plot required. At the end the heaped debris was again scattered evenly over the plot. Unfortunately shortly after the second application of Sulphate of Ammonia there was a very heavy storm and fears were entertained about the manure being washed away before entering the soil.

Use of Natural Yield Records.

Records of natural yield in pods per annum were taken over the whole block in 1931 to 1932 and in 1932 to 1933, and if possible these will be used to correct the yields of the experimental years, following the method of Sanders (11).

The numbers of pods harvested per half plot in the crop 1931 to 1932 are presented in Table 34 which represents the plan of the experiment.

Table 34.

E	S								W
	222	224	206	178	115	430	437	211	
	315	146	165	244	244	248	296	238	
	227	177	282	241	263	200	265	264	
	207	210	271	155	403	329	474	296	N

It will be noted that there is a general fertility gradient from East to West and from South to North. Combining the yields of pairs of half plots the analysis of variance is as shown in Table 35.

Table 35.

Analysis of Variance.

Soil Heterogeneity	Due to	D.F.	Sum of Squares.	Mean Square.
	Rows ..	3	32,140	10,713
	Cols. ..	3	104,340	34,780
	Treatments	3	3,107	1,036
	Error ..	6	60,687	10,115
	Total ..	15	200,274	

This shows that our hypothetical treatments are at the start significantly similar as regards yield.

The total Error Variance equals 7088.

The Standard Error of the difference between two treatment means = $\sqrt{\frac{7088 \times 2}{4}}$

A difference between tree means to be significant must exceed $\frac{1}{10} \times t \times \sqrt{\frac{7088 \times 2}{4}}$ where "t" = 2.262.

This amounts to 8.42 pods per tree.

The Mean Yield per tree over the whole block is 31.96 pods so that the increase necessary to be significant must be at least equal to 26.33 per cent. of the crop.

This figure is high but it agrees very well with those from previous Uniformity Trials.

Analysed on the basis of Phosphate Plots the Variance is slightly less (Table 36).

Table 36.

Analysis of Variance.

Soil Heterogeneity	Due to	D.F.	Sum of Squares.	Mean Square.
	Rows ..	3	16,069	5,356
	Cols. ..	7	90,235	12,891
	Treatment	1	1,875	1,875
	Error ..	20	115,981	5,799
	Total ..	31	224,160	

The Standard Error of the difference between two treatment means is $\sqrt{\frac{5612 \times 2}{16}}$ and the

necessary increased yield per tree must be not less than 6.89 pods to be significant. This is equivalent to a 21.6 per cent. increase.

In the second year of natural yield records the crop was smaller. The yields in total pods per half plot are given in Table 37.

Table 37.

		S								
E	273	233	251	176	43	300	290	205		
	330	192	87	157	181	220	255	236	W	
	139	112	205	134	172	248	149	151		
	152	136	45	66	321	262	213	109		
		N								

Treated as a 4 by 4 Latin Square the Analysis of Variance shows that "Error" has for some reason become much greater, being more than twice that of the first year. The yields within the plots during the second year were less variable than in

the first year, which happening to be a favourable year, allowed the potentially good bearers to outstrip the bulk of trees (Table 38).

Table 38.
Analysis of Variance.

Due to	D.F.	Sum of Squares.	Mean Square.
Rows ..	3	43,114	14,371
Cols. ..	3	55,085	18,362
Treatment ..	3	28,448	9,483
Error ..	6	109,088	18,181
Total ..	15	235,735	

A difference between tree means to be significant for any two treatments must now exceed

$$\frac{1}{16} \times 2.262 \times \sqrt{\frac{15282 \times 2}{4}} = 12.35 \text{ pods.}$$

The mean yield over the whole block = 23.61 pods so this increase is equivalent to 52.3 per cent. of the natural yield.

Treated on the basis of half plots the variance ascribable to error is 5294. Therefore a difference between treatment means in pods per tree must exceed 6.69 pods which is equivalent to an increase of 28.3 per cent.

It is interesting to note that in only one analysis does the required increase exceed 30 per cent., the figure calculated from the previous uniformity trials.

When the average plot yields of the two years is calculated there is a slight increase in precision. Thus for the whole plot analysis the variance is as follows (Table 39).

Table 39.
Analysis of Variance.

Due to	D.F.	Sum of Squares.	Mean Square.
Soil Heterogeneity..	6	73,332	12,222
Error ..	9	5,727	8,414
Total ..	15	149,059	

From this it is calculated that there must be an increase of 9.07 pods per tree due to treatment in order that the result may not be due to chance. This is equivalent to a mean yield increase of 32.6 per cent. The average of the increases required for the two years separately is $52.3 + 26.3$

$\frac{2}{2} = 39.3$ per cent. Hence there is a definite gain in precision by using the biennial average.

Similarly the Analysis for the mean half plot yields shows a slight increase in precision (Table 40).

Table 40.—*Analysis of Variance.*

Due to	D.F.	Sum of Squares.	Mean Square.
Soil Heterogeneity..	10	65,205	6,520.5
Error ..	21	94,928	4,520
Total ..	31	160,133	

The increased yield to be significant must average slightly more than 6.18 pods per tree. This is equivalent to a mean yield increase of 22.25 per cent.

The average of the increases necessary in the two years separately amounts to 24.95 per cent. Again there is definite gain in precision by using the biennial average.

Observations to be taken.

The yield data will include the number of pods harvested at each picking from every tree together with the number and weight of the beans inside each. In this way it may be possible to measure the effect if any of the fertilizers on actual bean size. It may be possible after measuring the pod value of a sample of 30 pods from any tree to use the average from these as an estimate of the True Mean Pod Value for the tree. This will save labour in dealing with heavy bearers.

In addition to the main yield factors other observations are being made on the canopy of the tree, the period of leaf change, the abundance or otherwise of flowers, fruit setting and finally wilting in young cherelles.

The phenomena of fruit setting and wilting play a major rôle in crop returns. It is quite probable that most trees could bear much heavier crops were they able to set fruit at favourable periods and to carry them over the embarrassing periods of youth. Indications have been obtained that soil nutrients play an important rôle in this respect and that increased crop may result not only from increased setting but also from decreased wilting of young fruit.

Provision has been made by the Chemical Section for recording environmental factors for comparison of the plot with others upon which environmental studies are also proceeding.

Summary.

A fertilizer experiment has been laid down by the Trinidad Department of Agriculture and Officers of the Cacao Research Scheme, incorporating the most recent advances in the technique of field experimentation as applicable to seedling plantation cacao. Any increases of yield observed are likely to be significant if of the order of 30 per cent. It is hoped that results will lay a basis for experimentation on genetically uniform cacao when the latter is available on a sufficient scale.

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STUDENT INVESTIGATIONS. 1932-1933.

Abstracts of Dissertations Submitted.

I. THE INTER-RELATION BETWEEN PIGMENT AND POD MORPHOLOGY IN CACAO BY W. E. FREEMAN, A.R.C.S.

THE paper opens with a discussion of the crop in general including the little that is known about pollination, and the problem of quality improvement. This leads up to one section of the subject under investigation namely the value of being able to predict the probable characters of the bean inside the pod from the external characters of the plant. The first section goes on to discuss the work of Van Buuren who up to the time of his death was engaged in classifying a large number of seedling progeny from one parent tree in Ceylon. The remainder of the first section explains the material and methods used in the present study.

Part II deals with the results which on account of their complexity have been summarised into a number of correlation tables.

Bean Colour and External Pod Pigment.—Bean colour was divided into six classes of which four were termed light and two dark. The most interesting observations come from the percentage of light beans in each case. The results bear out the work of Van Buuren, but to a less marked extent, in that there are indications of a negative correlation between pod pigment and bean pigment. The red or almost completely pigmented pods gave a light bean percentage of 21.76 while the remainder gave a percentage of only 14.55.

Bean Colour and Flush Colour.—In the case of flush colour (the colour of the immature leaves) no correlation was indicated at all except in the few trees which had no flush pigment at all. These gave a very high percentage of light beans, equal to 70.54.

Bean Colour and Axil Spot.—Axil spot, which is the term applied to the pigment at the base of the petiole was divided into three classes, as follows:—

- (a) Axil spot obviously present.
- (b) Axil spot faint.
- (c) Axil spot absent.

No correlation was found to exist between the presence or absence of axil spot and the percentage of light beans although later Freeman gives evidence of a very well marked positive correlation between axil spot and pod colour.

Bean Colour and Pod Shape.—Pods with ridges have definitely more light beans than those which are smooth. Ridging is a character which has been brought in from possible Criollo ancestors whilst the smooth pod is said to be typical of pure Calabacillo.

Bottle-neck, a stalk end constriction found in many pods, is often regarded as another Criollo character but the percentage of light beans in these pods is smaller than in pods without this neck constriction.

As regards apex, pods with a very long point, which is often curved, were found to contain an average of 22 per cent. light beans as opposed to 15 per cent. found in pods with merely a blunt point or no point at all. The point is probably a very strong Criollo character since it is present in all types of Central American Criollos.

Naturally a pod with a long point must have a large ratio of length to diameter and so Freeman finds that the percentage of light beans in pods with a high ratio is 22.28 while in the low ratio types the percentage is only 14.59.

The author points out that in each case the type with the largest percentage of light beans is invariably the one which exhibits the greatest number of Criollo genes and such being the case the cumulative effect should be well marked. Thus he finds that types with a red pod, a long point and deep furrows give an average of 27.73 per cent. light beans while types of the opposite characters, namely green pod, short point and smooth surface have merely 8.91 per cent. of light beans. When the character of bottle neck is introduced then the distinction is less obvious emphasising the fact again that bottle neck is not a Criollo characteristic.

In summarising his analysis of bean correlations the author states that the greatest percentage of light beans occurs in pods which have the greatest obvious number of Criollo genes.

Other Correlations.—Under the heading of 'Other Correlations' Freeman finds that the association between axil spot and flush colour shows a strong correlation with a coefficient of 0.80. Between pod colour and flush colour there is a general correlation of 0.85. Taken together these two support Harland and Frecheville (12) who find a positive correlation between pod colour and presence of axil spot.

The correlation between warts and ridges is also positive with a coefficient of 0.83.

As an appendix the author shows that bean colour is independent of the position which a pod occupies on the tree. He points out that his data do not support Wellensiek's hypothesis (13) that there is one basal factor responsible for bean pigment together with several intensifiers. However in his tables, four of seven trees examined gave a percentage of light beans lying between 20 and 30 per cent. while two of the others give but 1 per cent. and can hardly be said to segregate white beans at all. This point is discussed elsewhere in this Report.

F. J. P.

References.

- (12) *Genetica* 9 (1927) 279-88.
- (13) *Archief v. d. Koffiecultuur* 5 (1931) 217-33.

2. FERTILITY IN CACAO BY J. MARSHALL, A.R.C.S.

The trees used for this particular study consisted of twenty-one average individuals growing under normal estate conditions and planted at a distance of approximately 13 feet apart. Hand pollinations were begun in October and up to the end of January flowering was moderate. After that period flowering was poor.

The bulk of the pollinations were thus made during the first period, and seven of the trees proved consistently to be self-incompatible. The remaining fourteen set varying amounts of fruit from the controlled pollinations. A survival for six days after pollination was taken as a criterion of setting, for after that time the loss which occurs may be due to other causes. At six days the ovary has swollen distinctly and grown to a length of 4 mms.

The self-compatible trees are discussed first. Marshall points out that the range of setting percentages varies from 72 per cent. to 10.8 per cent., a wide range, but the behaviour of each tree is fairly consistent. Setting was generally high in October, decreased in November but in January had regained its October level. The drop in November is statistically significant and must be a response to adverse environmental conditions.

The correlation between setting and the rainfall for a week following pollination is negative and significantly high, suggesting that humidity relations decide whether a flower, once adequately pollinated shall set or abscise. Rainfall also has a very depressing effect on the degree of flowering. The author points out that humidity and not actual rainfall may be the real cause of the decrease in setting and flowering.

As regards the relationships between flowering and setting no correlation could be found. In the discussion which follows the probable causes of flower fall are reviewed and the way in which pollination may delay abscission is entered into. Marshall finds some evidence to suggest that at about 3 days after pollination there occurs a critical period in the life of the young cherrille. He suggests this is connected with the first divisions of the endosperm cells which Cheesman finds to occur at this time.

Since the trees are consistent in the relative proportions of pollinations which set it is evident that genetic factors underlie problems of self-compatibility although physiological factors may govern their expression. The author discusses the effects of rainfall in this connection and finds full evidence to support Dunlop's and Skidmore's correlations (14) (15).

From the seven self-incompatible trees only 3 cherrilles set as a result of more than 500 pollinations. These are considered to be accidents

caused by natural cross pollination. The total lack of setting on self pollinating these trees remains consistent right up to May when the work was discontinued. In order to test whether pollination was actually at fault the author tried the effect of pollen of different ages on stigmas of different ages but in no case was a set registered. All the trees were found to be cross compatible with neighbouring self-compatible trees. One of the seven trees found to be setting naturally was bagged over the main branches and trunk. Insects which were already on the tree were not removed. Although setting continued outside the bag no set was registered inside proving in the author's estimation that for successful setting, pollen must be brought from a neighbouring tree.

Further when self-incompatible trees were intercrossed no set was registered.

In the discussion at the end the author points out that some of the trees which were not very healthy may have been self-incompatible on that account. In discussing insect relations the suggestion is made that in self-compatible trees the young cherrilles form a splendid feeding ground for numerous sucking insects and that the presence of an initial few may encourage others, resulting in more pollination, more setting and again more insects. The possibility of wind pollination is discussed and the conclusion is reached that this appears structurally impossible since the pollen is sticky and is discharged into the hoods of the petals. Both in January and May the author noticed there was more than the average setting on self-incompatible trees but of 2,000 flowers noted in February to April only 2 set. He suggests there are peaks when natural crossing agents are more abundant than normally.

In conclusion it is considered that fruitfulness can be limited by the amount of setting and that all trees do not carry their maximum crops. Lack of adequate pollination may be an important problem for, unless flowers are pollinated, they cannot set fruit even under favourable conditions. Evidence thus points to the fact that only a few trees in the field are efficient producers of cacao and that the amount of crop depends on a very fine balance between physiological and genetical factors.

F. J. P.

References.

- (14) Dunlop, W. R.—Rainfall and Crop Yield, with particular reference to cacao in Trinidad. *Nature* 115 No. 2884 repr. in *Tropical Agriculture* 2 (1925) 109.
- (15) Skidmore, C. L.—Indications of existence of correlation between rainfall and number of cacao pods harvested. *Gold Coast Dept. Agr. Year Book* 1928 (*Bull.* 16), 114-120.

B.—CHEMICAL AND ECOLOGICAL SECTION.**THE CHEMICAL PROGRAMME OF 1933.**

BY F. HARDY.

THE main lines of work followed during 1933 have consisted in (I) the completion and the publication of results of a detailed soil survey of some 80 square miles of cacao land in the Montserrat District of Trinidad, (II) the reaping and the statistical analysis of yield data of field experiments with phosphate and potash manures, based on the findings of soil surveys, (III) the chemical analysis of leaf material obtained from cacao trees growing on the experimental manurial plots, in an attempt to assess the nutrient requirements of cacao, and (IV) a critical examination of meteorological data collected during a three years' period at two contrasted "good" and "bad" sites growing cacao under estate conditions, and (for comparison) at the College Meteorological Station.

Much of this work lies along lines indicated in the previous two Annual Reports on Cacao Research. The present stage reached in each of these investigations is described by Mr. McDonald in the following four parts of this section of the third year's report.

(I) Cacao Soil Surveys.

A Report on the cacao soils of the Montserrat District of Trinidad, embodying the results of a detailed soil survey, based mainly on the examination of a great number of soil profiles was published in October, 1933. The main conclusions are summarised and discussed by Mr. McDonald in a following article, in which a general comparison between these cacao soils and those occurring in Grenada and in Tobago is attempted.

The cacao soils of the three regions are derived from entirely different parent rock materials. Nevertheless, the better-yielding soils of each region are sharply contrasted with the poor-yielding soils in respect mainly to content of available phosphate, and the carbon-nitrogen ratio of their organic matter component. These fundamental differences have suggested specific manurial experiments, some of which are described in the second article.

(II) Manurial Experiments on Cacao.

So far, six separate experiments involving phosphate, and in some cases potash, have been laid down, five in Trinidad and one in Grenada. The yield data obtained in three of the experiments for the 1932-33 crop are considered in detail by Mr. McDonald, and important conclusions based on their statistical analysis are stated and discussed. Increases of the order of 50 per cent. have been obtained in these three experiments. The data also furnished useful information regarding the technique of manurial trials on cacao, which has proved of great service in the designing of further experiments now being initiated.

(III) The Relationship between Nutrient Supply and the Chemical Composition of the Cacao Tree.

Much progress has been made during the past year in the diagnosis of nutrient deficiencies by means of chemical analysis of the ash of cacao leaves. In this investigation, the services of the chemical analytical staff of the College, under Mr. G. Rodriguez, have proved of great value.

During 1932, attention was confined mainly to a comparison of the chemical composition of old and young cacao leaves and of cacao beans collected from "good" and "bad" plots. Chemical analysis of cacao beans proved to be unpromising in view of the heterogeneous nature of the tree population of each plot, owing to the mixture of genetic strains. On the other hand, the results obtained by the analysis of leaves showed considerable differences in composition of the mineral matter (leaf ash) for cacao trees growing in the contrasted sites, and for cacao trees differently affected by infestation of Thrips, which is the most serious insect pest of cacao in Trinidad. The differences were most clearly indicated by the nitrogen/potash ratio, which seems to furnish a reliable index of "physiological condition" of the tree that partly determines its behaviour under fluctuating environmental moisture conditions.

During the past year, the scope of the investigation has been considerably widened into a general study of "nutrient balance" between the three elements, nitrogen; phosphorus and potassium, necessary for vigorous growth and high productivity. In this connection, consideration has been given to the results of recent researches on fruit trees conducted in England, the United States of America and elsewhere. This has necessitated an extensive search into the literature of the subject, and a summary of these researches has been included as part of the article dealing with this phase of our investigations.

The question is one of considerable complexity, but the preliminary results suggest that leaf ash analysis furnishes a means of diagnosing nutrient deficiencies and nutrient requirements that may render possible the more exact interpretation of the results of manurial experiments, and the formulation of balanced manurial mixtures for application to the cacao tree growing in different types of soil and under various sorts of atmospheric and climatic environments. The practical value of such precise knowledge would be considerable, but its accumulation entails a great amount of careful chemical analytical work, which is time-absorbing and tedious. Nevertheless, it is intended further to pursue this line of investigation as future opportunity allows.

The utilisation of material produced by trees growing on the plots of the different manurial experiments now in progress or in the process of

initiation, will help greatly in the prosecution of this inquiry. The two phases of the work—manurial experiments and leaf analysis—are concurrent; their study with respects to the cacao tree and the particular growth conditions represented in Trinidad will occupy most of the time and attention of the chemical officer during the next year.

Owing to the greater importance of the subjects above-mentioned, the progress of minor soil and plant studies will not be described in the present report.

(IV) Meteorological and Ecological Studies.

The accumulation of data from the two contrasted plots, fully described in the previous annual reports, has continued throughout the year. Sufficient records have been obtained to warrant at this stage a detailed statistical analysis of the inter-relationships that exist between various atmospheric factors which are involved in the evaporation of water from soil and plant at these two sites, as well as at the College Meteorological Station, where no wind-breaks nor overhead shade trees occur. The rate at which a moist surface dries depends on the evaporating ability of the air, which in turn depends on various meteorological factors, such as relative humidity (or saturation deficit), air movement (or wind velocity) and radiation (or degree of insolation). It can be measured directly by the Livingston atmometer, a rather elaborate instrument consisting essentially of a porous porcelain hollow sphere, full of water, connected with a reservoir whose rate of water loss can be determined by periodic (weekly or daily) measurements.

For any one particular environment, the statistical analyses have shown that rate of evaporation, as assessed by atmometer readings, is closely correlated with relative humidity, and this, in turn, with the minimum daily humidity, realised in Trinidad at 2 p.m. A sufficiently accurate measure of the degree of fluctuation of atmospheric evaporating ability within a cacao field throughout the year can therefore be obtained by daily measurements of relative humidity at 2 p.m. For this purpose, it is recommended that a cheap form of pocket paper hygrometer be employed. Records obtained by this means would enable the planter to gauge the effect of changing weather conditions on the cacao trees growing in any particular site, and would help him the more clearly to interpret his observations on such events as leaf flushing, fruit setting and pod shrivelling.

Comparison between widely different environments, such as open, exposed sites as contrasted with well sheltered sites, cannot accurately be made, however, by such simple means, chiefly because variations in wind velocity and air currents markedly affect the rate of water evaporation. This air-movement factor does not affect relative humidity, so that hygrometer records cannot be expected to differentiate between environments of varying exposure to wind. Recourse must therefore be made in such cases to the atmometer, which integrates *all* the factors that decide atmospheric evaporating ability. A full appreciation of these and other related facts stressed by Mr. McDonald in Part IV of his report should guide the ecological investigator in his detailed studies of plant environments, and should give greater definition to problems concerning the effects of wind-belts, shelter-belts and shade trees.

14th March, 1934.

PART I.

CACAO SOIL SURVEYS.

BY J. A. McDONALD,
(*Chemist for Cacao Research*).

(I) Introduction.

DURING 1933, the survey of the cacao soils of the Montserrat District of Trinidad was completed, and a detailed report of the work was published (1). This report forms Part VII of the "Studies in West Indian Soils" which comprise accounts of a series of soil surveys carried out by the Chemistry Department of the Imperial College of Tropical Agriculture under Professor Hardy.

Two other reports (2), (3) in this series have dealt with soils upon which cacao is grown, namely Part III (The Cacao Soils of Tobago), and Part IV (The Cacao Soils of Grenada). In the latest report therefore, the opportunity has been taken of comparing the cacao soils of the Montserrat District of Trinidad with those of Tobago and

Grenada. It will be of interest to give a summary at this place of our main conclusions regarding the chief characters and nutrient relationships of good cacao soils.

(II) General Comparison of the Cacao Soils of Trinidad, Tobago and Grenada.

The climatic conditions of temperature, rainfall and humidity are very similar in Trinidad, Tobago and Grenada, but the geological formations from which the cacao soils of these three regions have been developed are very different. The soils of Grenada are derived from basic and intermediate igneous rocks, the soils of Tobago are derived from basic igneous rocks, and from metamorphic sedimentary rocks, while the soils of the Central

Range, Trinidad, are derived from marine and estuarine sedimentary deposits. From a general consideration of the geology of these three different regions, one would expect the soils of Grenada and Tobago to be potentially more fertile than the soils of the Central Range of Trinidad, since, given the same degree of weathering, the soils derived from igneous rocks should contain a greater proportion of fresh minerals and therefore of basic substances, such as potash, lime and magnesia. The fertility of the cacao soils of the Montserrat District of Trinidad, however, has been greatly enhanced by outcrops of calcareous glauconitic sandstones and glauconitic sands which closely resemble Greensand. These Greensand deposits are very rich in phosphate and potash, and have given rise to the famous Chocolate Soil and the better types of Brasso Sand Soil of the Montserrat District of Trinidad, which undoubtedly have greater natural fertility than any other cacao soil that we have examined. These Greensand deposits may be termed the centre of fertility of the Montserrat District of Trinidad, for the fertility of the soil

decreases very rapidly as one moves away from this area. For example, the Talparo Clay Soil and the Charuma Clay Soil which occur along the foothills of the Central Range lying to the north and south of the Montserrat District, are soils of extremely low fertility, and quite unsuited to the growth of cacao.

In Table I, comparison is made between the chief physical and chemical characters of good and bad cacao soils for the three different West Indies regions. The figures given represent average values computed from a very large number of samples in each instance.

The very high value for available phosphate shown by the "good" Trinidad soils is due to the very high phosphate content found in the Chocolate Soil. It will be noted that the Trinidad soils contain rather low amounts of available potash compared with Grenada soils. Furthermore, when compared with Grenada and Tobago soils, the Trinidad soils exhibit relatively high contents of organic matter and of nitrogen, and a very much narrower C/N ratio.

Table I.

Comparison between "Good" and "Bad" Cacao Soils; (A) Montserrat District (Trinidad), (B) Grenada and (C) Tobago. Topsoil and Subsoil.

(Average Values of Laboratory Data.)

"Good" Soil; Over 8 bags of dry fermented cacao beans per 1,000 pickets.

"Bad" Soil; 8 bags or under of dry fermented cacao beans per 1,000 pickets.

TOPSOILS (SURFACE SIX-INCH LAYER).										
Region and Productivity Category.	Texture. (I.T.)	Reaction. (pH)	Org. Mat. %	Nitrogen. %	C/N Ratio.	Avail. Nutr. (mhos $\times 10^{-6}$)	Rate of Soln. $\times 10^{-6}$	Avail. $P_2O_5^*$ (p.p.m.)	Avail. $K_2O^\dagger$	
<i>Montserrat District (Trinidad) Cacao Soils.</i>										
"Good"	40	6.9	4.0	0.33	7.1	216	183	149	254	
"Bad"	32	5.8	2.5	0.24	5.9	131	78	32	119	
<i>(B) Grenada Cacao Soils.</i>										
"Good"	34	7.4	2.8	0.20	8.0	135	88	85	430	
"Bad"	41	6.8	2.7	0.23	6.7	108	61	33	335	
<i>(C) Tobago Cacao Soils.</i>										
"Good"	32	6.7	3.5	0.24	8.3	171	169	63	—	
"Bad"	37	6.6	2.9	0.25	6.8	175	158	24	—	
SUBSOILS (SECOND SIX-INCH LAYER)										
<i>(A) Montserrat District (Trinidad) Cacao Soils.</i>										
"Good"	35	6.7	1.3	0.13	5.3	86	46	110	—	
"Bad"	30	5.7	0.9	0.11	4.1	89	27	57	—	
<i>(B) Grenada Cacao Soils.</i>										
"Good"	35	7.3	1.2	0.12	6.0	78	32	29	—	
"Bad"	42	6.6	1.5	0.15	5.7	65	26	14	—	
<i>(C) Tobago Cacao Soils.</i>										
"Good"	27	6.6	1.3	0.11	6.9	98	57	—	—	
"Bad"	35	6.5	1.3	0.12	6.4	100	57	—	—	

* Deficiency in *phosphate* may tentatively be taken as indicated by values below about 80 p.p.m. for clay soils, and about 50 p.p.m. for sandy soils.

† Deficiency in *potash* may tentatively be taken as indicated by values below about 150 p.p.m. for clay soils, and about 100 p.p.m. for sandy soils.

(III) The Physical and Chemical Characteristics of Good Cacao Soils.*

(a) *Texture and Physical Condition.*—The cacao soils so far examined vary from clays to light sands, and productive cacao occurs on both heavy and light-textured soils. There is abundant evidence, however, that one of the primary requirements of a good cacao soil is an even moisture status, that is, the soil must not be liable to sudden or extreme fluctuations in its moisture content. Light sandy soils therefore are only suitable for cacao cultivation under West Indian climatic conditions (where there is a marked dry season) when they occur in well-watered, sheltered localities, such as occur along river valleys and vegas. On the other hand, most of the compact clay soil types appear to suffer from inadequate natural under-drainage and aeration, as indicated by the pronounced mottling of the middle zone of the profiles.

(b) *Reaction (pH value).*—No evidence has yet been adduced to show that the cacao tree in the West Indies is restricted in its soil reaction requirements as are many other cultivated plants; indeed, other things being equal, it appears to thrive best in a soil of slightly acidic reaction. In Grenada and Tobago, soil reaction appears definitely not to be a factor controlling the growth of cacao, for the reaction range of good and bad cacao soils is approximately the same. In the Montserrat District of Trinidad, the good clay soils are all very definitely more alkaline than the bad clay soils, but this difference does not apply to the sandy soils. The significant difference in reaction between the good and bad clay soils in this area is merely an expression of the fact that the good clay soils possess a higher lime status, which greatly improves their physical properties, and thus ameliorates their water relations, the importance of which has been already stressed. It would appear, therefore that even though the cacao tree may be tolerant of a wide range of soil reaction, nevertheless a highly acidic reaction of heavy clay soils may be taken as a sign of physical

soil conditions unsuitable for the growth of cacao. In such cases the application of lime would undoubtedly be beneficial, not because of the reduction in soil acidity as such, but because of the improvement which is thereby brought about in the physical properties of the soil.

(c) *Nitrogen.*—There is no significant difference in the total nitrogen content of the good and bad West Indian cacao soils so far examined. This fact, when considered together with other evidence relating to the organic matter content of cacao soils and the Carbon/Nitrogen ratio of the organic matter fraction, leads to the conclusion that the low-yielding cacao soils are relatively well provided with nitrogen.

(d) *Organic Matter.*—In view of the essential differences in cultivation practices adopted in the three areas under discussion, the relative importance of soil organic matter must be considered for each area separately. The good cacao soils of the Montserrat District of Trinidad (particularly the clayey representatives) have a definitely higher content of organic matter than the bad soils. In view of the fact that there is no significant difference in nitrogen content, this feature suggests that the rôle of organic matter in these soils is not solely that of a source of nitrogen. It is probable that the importance of the organic matter component lies in its content of mineral nutrients. It is known that orchard crops and forest trees induce a circulation of inorganic salts in the soil. Nutrients from lower layers are transported upwards, and temporarily fixed in leaves, twigs and flowers. In due course, they are returned to the soil surface, where they are eventually liberated through decomposition. In this way, there is partial replacement of the chemical nutrient substances which are continuously being removed by successive crops. In Trinidad, cacao cultivation immediately followed the clearing of virgin forest, and, since implemental tillage is seldom used, the upper layers of natural soil are for the most part undisturbed. Also the replacement in the soil of chemical nutrient substances by means of the application of artificial fertilisers is seldom practised. It is not surprising therefore that the organic matter content of the soil has a close relationship to yielding capacity of the cacao tree, since it is probable that the only replacement of chemical nutrients is due to the decomposition of the organic matter.

In Grenada, cultivation of the top soil to a depth of six to twelve inches is a general practice, and artificial manures have been frequently applied. Under these conditions of cultivation, one would not expect the soil organic matter to be of such great importance from the point of view of supply of chemical nutrients. It is of interest therefore to note that the analytical data show that there is no significant difference in the organic matter content of the high-yielding and low-yielding cacao soils of Grenada.

* In order to compare the nutrient status of the various soil types examined, the laboratory data appertaining to the surface six-inch layer, and to the second six-inch layer, were statistically treated by the analysis of variance method. The sites where the soil samples were procured were classified into "good" and "bad," in accordance with estates yield data. Sites which yielded over eight bags (of 165 lb.) of dried, fermented cacao beans per 1,000 pickets were classified as good, and sites which yielded eight bags or under per 1,000 pickets were classified as bad. The top-soils (surface six-inch layer) in most cases alone were compared, since the laboratory data clearly show that the greater amount of nutrient substances are contained in a relatively shallow surface layer, where they represent concentrated accumulations caused by the return of plant residues to the soil. The laboratory data and the methods by which the following conclusions were derived are presented in full in the above-mentioned reports (1), (2), (3).

As regards methods of cultivation, Tobago is in an intermediate position between Trinidad and Grenada. In Tobago, implemental tillage is not usually practised, nor are artificial manures generally used. Most of the cacao cultivation, however, is now growing on land which was formerly cultivated in sugar-cane, and the soil has therefore been subjected to continuous and thorough hand-working during the long period of time when sugar formed the staple crop of the island. For Tobago, the analytical data show that the good cacao soils contain a larger amount of organic matter than the bad cacao soils, but the difference is not nearly so marked as it is for Trinidad. For cacao soils also there is a high degree of correlation between organic matter content and "rate of solution" values. This definitely shows that soils containing the larger amounts of organic matter are also capable of yielding the larger amounts of plant nutrients. The collected evidence from the three different areas thus shows that the organic matter content of cacao soils bears an important relationship to their yielding capacity, and the chief function of the organic matter would appear to be that of a supplier of plant nutrients. In support of this theory, it has been shown that the organic matter content of cacao soils is more closely related to their productivity in areas where the use of artificial fertilisers is not a customary practice.

(e) *Carbon/Nitrogen Ratio*.—The most highly significant difference between the good soils and the bad in these three different cacao-growing areas is shown by Carbon/Nitrogen ratios of the soil organic matter component. The average ratio for good soils is always greater than that for bad soils. The numerical average values of the ratio are not identical for the different regions (Table I), but are appreciably lowest in the soils of the Montserrat District of Trinidad. Although the full meaning of this characteristic is not yet understood, it is known that high Carbon/Nitrogen ratios are associated with the presence of undecomposed plant residues in the soil, whilst low ratios indicate that the soil organic matter is highly humified, and its nitrogenous compounds are more easily transformed into readily-available nutrients, such as nitrates. This finding favours the view that the low-yielding cacao soils so far examined in the British West Indies are relatively well provided with nitrogen.

(f) *Available Phosphate*.—There is a very marked difference in phosphate status between the good and the bad cacao soils so far examined, and it may be said that one of the most striking features revealed by our examination of the cacao soils of the British West Indies is this marked deficiency in phosphate of the poorer types of soil, a discovery which has led to inauguration of special field experiments designed to test the effect of different dressings of superphosphate on the yield of cacao (see Part II).

(g) *Available Potash*.—In contrast to the case of phosphate, the analytical data demonstrate no very significant difference between the amounts of available potash present in good and bad cacao soils. Usually the good soils contain greater quantities of potash, notably the sandy types of soil, but many of the low-yielding clay soils seem to contain adequate potash supplies. It has been shown elsewhere (4) that the susceptibility of the cacao tree to attacks by Thrips may be influenced by potash deficiency, or more strictly, by deficiency of potash relative to nitrogen.

(h) *Harmful Factors*.—In the Montserrat District of Trinidad, many of the poorer clay types of cacao soils contain abnormal concentrations of sulphate-ion, derived from dissolved gypsum, which appear to exert definite deleterious effects on the cacao cultivation. For the Brasso Clay soil type, this characteristic clearly distinguishes the bad soils from the good soils.

(IV) General Conclusions: the Nutrient Relation of Cacao Soils.

The main soil factors that control plant growth are (i) water supply, (ii) nutrient supply, (iii) air supply, (iv) root room, (v) absence of harmful soil factors, and (vi) soil temperature. Many of these factors are interdependent, for instance water supply and nutrient supply (since plant nutrients are believed to enter the root system mainly in solution). Harmful factors include (a) excessive soil acidity and alkalinity (unsuitable reaction), (b) certain salts (such as chlorides and sulphates) present in excessive concentration, (c) undesirable micro-organisms, and (d) toxic organic substances which sometimes accumulate in soils that are badly drained and badly aerated.

The West Indian cacao soils which have been so far examined seem to vary widely in the degrees to which these different soil factors operate. Thus, the water supply and air supply factors in the more porous and permeable soil types appear to be satisfactory where proper cultivation is practised, and when climatic fluctuations are not extreme. On the other hand, most of the compact clay soil types appear to suffer from inadequate drainage and aeration. In view of the known sensitivity of the cacao tree to sudden and extreme fluctuations in those environmental factors that control water supply, texture and general drainage conditions must be considered to be important factors governing the suitability of a soil for the growth of cacao. As regards harmful soil factors (apart from organic toxins), excessive acidity or alkalinity rarely seems to exercise a limiting rôle in the growth of established cacao. Excessive concentration of sulphate-ion, derived from dissolved gypsum, does however, appear to exert a harmful effect in certain of the clay types of soil of the Montserrat District of Trinidad. With regard to nutrient supply, it has been concluded that, where water relations and general cultivation conditions (including botanical factors such as genetic type of cacao tree) are

evidently satisfactory, *nutrient supply* is the chief factor controlling the growth of the cacao tree in the different types of soil occurring within the regions surveyed.

It has been shown that the cacao soils of the three areas in the West Indies are of markedly different origin, and it is therefore of great importance to note that a number of the main findings of our soil survey work with regard to the nutrient relationships of cacao soils apply to all three areas which have been investigated. This fact indicates that these findings may be of fundamental importance wherever cacao is grown. Evidence is rapidly being accumulated in support of the view that different species of crop plants require for maximum yield, nitrogen, phosphorus and potassium in very definite ratio. For each plant species producing its best growth, there appears to be need of a particular balance between the three essential nutrient elements. Hence the problems of nutrient supply for the cacao crop should in future be studied from this point of view, and soil analyses should be interpreted, not solely in terms of total content or deficiencies of nitrogen, phosphate and potash, but in terms of *balanced ratios*. Attempts to apply this rule to data obtained in the studies of cacao soils might eventually lead to more definite conclusions regarding the nutrient requirements of the cacao tree, and to sounder systems of manuring. For instance, when the supply of nitrogen in the soil is adequate or in excess, additions of phosphate and potash might be expected to produce increased yields. Similarly, when potash or phosphate is present in excess, dressings of suitable nitrogenous manures should be highly beneficial. The evidence so far obtained from the investigation of West Indian cacao soils has indicated a lack of balance in the nutrient status of many of the poorer yielding soils. Phosphate in particular has been shown to be deficient, and potash deficiency has also been indicated in certain particular cases, though not to such a marked extent. These findings do not necessarily mean that nitrogen is present in inadequate or excessive amounts in such soils, but rather that indiscriminate nitrogenous manuring may be wasteful, if not definitely harmful, unless the deficiencies of phosphate and potash are first remedied. On the other hand, it is conceivable that certain good soil types, containing high amounts of available phosphate and potash, might give even greater yields when treated with nitrogenous manures. In this connection it is important to remember that, even though the cacao tree may require nutrient elements in definite ratio, the manurial needs of different types of soil appear also to be highly specific, and therefore detailed soil survey work will be an essential preliminary to any definite system of manuring cacao soils in a particular area.

(V) Summary.

(i) Reference has been made to recent soil surveys of three different areas in the British West Indies.

(ii) Based on the evidence obtained from these three soil surveys, the following conclusions regarding the physical and chemical characteristics of good cacao soils have been reached :—

(a) *Texture* :—The physical properties of good cacao soils are such that the soil is not subject to sudden or extreme fluctuations in its moisture status. Thus, optimum texture conditions will vary with climatic and environmental factors. Good natural drainage is essential, but light sandy soils are only suitable for the growth of cacao in well sheltered, moist environments.

(b) *Reaction (pH value)* :—The cacao tree appears to be tolerant of a wide range of soil reaction, the optimum reaction being slightly on the acid side of neutrality. A highly acidic reaction occurring in heavy clay soils may be taken as a sign of physical conditions of the soil unsuitable for the growth of cacao.

(c) *Organic Matter Content* :—The organic matter content of West Indian cacao soils is closely related to their productivity. It is thought that the chief function of organic matter is as a supplier of mineral nutrients which are liberated and fixed when the organic matter decomposes. In support of this theory, it has been shown that the organic matter content of the soil is more closely related to its productivity in those areas where the use of artificial fertilisers is not a customary practice.

(d) *Nitrogen Content* :—No relationship has been found between the total nitrogen content and the yielding capacity of any of the cacao soils so far examined.

(e) *C/N Ratios* :—There is a marked difference between the good and the bad cacao soils in the Carbon-Nitrogen ratio of the soil organic matter component. The average ratio for good soils is always greater than that for bad soils. This finding favours the view that the low-yielding cacao soils so far examined in the British West Indies are relatively well provided with nitrogen.

(f) *Available Phosphate* :—One of the most striking characteristics of high-yielding cacao soils is a high content of available phosphate, and conversely a widespread deficiency of phosphate has been shown on low-yielding cacao soils.

(g) *Available Potash* :—High yielding cacao soils generally have a high content of available potash, but the contrast between high and low-yielding soils is not nearly so marked as in the case of phosphate. Deficiency of potash may be a factor contributing to susceptibility of the cacao tree to Thrips attack.

(h) *Harmful Factors* :—Many of the clay soils of the Montserrat District of Trinidad appear to contain definitely harmful concentrations of sulphate-ion derived from dissolved gypsum.

(iii) Even though the soils of the three different areas are derived from widely different geological formations, it has been shown that many of the

findings of the soil surveys apply to all three areas. This indicates that the findings may be of fundamental importance, and are not of merely local importance in each area surveyed.

(iv) The problem of increasing the yield of cacao by means of artificial fertilisers has been discussed from the point of view of balanced nutrition. It has been pointed out that there is a *lack of balance* in the nutrient status of low-yielding cacao soils, and the proper manurial practices involved in their improvement have been indicated.

(VI) References.

- (1) McDonald, J. A., Hardy, F. and Rodriguez, G.—“Studies in West Indian Soils. (VII) Report on the Cacao Soils of Trinidad, (A) Montserrat District.” Oct., 1933.
- (2) Hardy, F., Akhurst, C. G. and Griffith, G.—“Studies in West Indian Soils. (III) Report on the Cacao Soils of Tobago.” Feb., 1931.
- (3) Hardy, F., McDonald, J. A. and Rodriguez, G.—“Studies in West Indian Soils. (IV) Report on the Cacao Soils of Grenada.” Dec., 1932.
- (4) McDonald, J. A.—*Second Annual Report on Cacao Research*, 1932. (B) Chemical and Ecological Section, Pt. III. 1933 Trinidad, Imperial College of Tropical Agriculture.

PART II.

MANURIAL EXPERIMENTS ON CACAO.

BY J. A. McDONALD
(*Chemist for Cacao Research.*)

(I) Introduction.

Any scheme of soil investigation which involves the estimation of crop manurial requirements must necessarily include a definite scheme of field experiments, since it is only by means of the field manurial trial that the quantitative increases in yield due to certain treatments can be determined, and the optimum amounts of fertilisers to apply from an economic point of view. Manurial field experiments on perennial tropical crops, such as cacao, unfortunately have a great many serious defects, and it is nowadays generally conceded that manurial experiments on perennial crops should be carried out only in conjunction with soil surveys, which involve detailed examination of the physical and chemical properties of the soil. In this connection, it is of interest to note the views of Vageler and of Page, who have stressed the interdependence of soil survey work and field manurial trials. Thus Vageler (1), in discussing the function and utility of manurial experiments on perennial tropical crops, states “There is good reason for treating the manurial experiment, whether large or small, simply as a test of the results of soil analysis, a purpose which it admirably serves”, whilst Page (2), discussing the practical utility of soil analysis, states “The proper function of soil analysis for the diagnosis of the manurial requirements of the soil is in connection with a soil survey, associated with a properly-designed scheme of field experiments”.

For established cacao areas in Trinidad, one serious difficulty in the way of field experiments lies in the presence of numerous shade trees, which must take a large share of the manure; another difficulty lies in the extremely variable stand of cacao which occurs in the average cacao field. These complicating factors often cause the variability in the natural yield of plots to be so large, that, unless very big yield increases are obtained, it is difficult or impossible to prove

statistically that the increases obtained are really due to the manure applied, and not merely to chance variation between the plots. This aspect of the question has been investigated by the Botanical Section of Cacao Research (3), and it has been shown that, making use of a 4×4 Latin square layout, even on cacao cultivation where the trees are uniform in age, an increase of over 30 per cent. in yield is necessary before the possibility of the increase being due to chance can be eliminated. Such a strict requirement obviously imposes a serious drawback to the use of manurial field experiments for accurately determining nutrient needs and crop responses. For a crop such as cacao, field manurial experiments are therefore unlikely to yield satisfactory results unless they are based on previous soil survey work. The detailed information obtained from soil surveys furnishes indications of the deficiencies from which a soil is suffering, and shows the particular treatments which are most likely to yield increased returns. In this way, a large amount of time and trouble is saved in testing haphazard or arbitrary treatments which may eventually prove to confer no benefit. Furthermore, the use of soil maps enables experimental sites to be selected which are truly representative of the soil types occurring within an area where the crop is grown. By means of the soil map also, extreme variations in fertility within an experimental block can be largely eliminated. Such, then, is the plan which has been followed by the Chemical Section of Cacao Research in investigating the manurial requirements of the cacao crop. The soil survey work has now reached a stage where definite recommendations may be made concerning manurial treatments, and the logical continuation of this work in the near future should consist of a definite series of field experiments designed to test the main findings of the cacao soil surveys.

Present Series of Experiments.

In Part I of this report, the main conclusions of the cacao soil surveys are presented, and it is there shown that one of the most important findings is a widespread deficiency of phosphate in poor-yielding cacao soils. The preliminary field experiments have been designed, therefore, to test the responses of the cacao tree to applications of soluble phosphate manures under different conditions of soil and atmospheric environment. Experimental blocks have been laid down in six different localities, five in Trinidad and one in Grenada. The sites of the different experiments are as follows:—

- (1) Torrecilla Estate, Arima, Trinidad.
- (2) Las Hermanas Estate, San Rafael, Trinidad.
- (3) River Estate, Diego Martin, Trinidad.
- (4) Sta. Serviera Estate, Brasso, Trinidad.
- (5) Rio Claro, Trinidad.
- (6) Carriere Estate, Grenada.

The chief physical and chemical characteristics of the soil types at five of the different sites are indicated in Table I.

It will be seen from Table I that the different experiments are situated on soil types which differ widely in physical and chemical characters, and range from a fairly light sand to a medium-heavy clay. Each of these soils represents a type upon which large areas of cacao are grown in Trinidad and Grenada. Experiments (1), (2) and (4) are under our direct supervision; the other experiments are under the charge of the Trinidad

Department of Agriculture, to whom we are indebted for the supervision of the experiments and the collection of yield records.

Type of Layout.—The general type of layout adopted has been the 4 × 4 Latin square. Each individual plot consists of 18 trees, as recommended by Cheesman and Pound (3), and there are two guard rows between each plot. Each experimental block therefore covers nearly two acres. The arrangement of the plots at Torrecilla and at Las Hermanas is shown in Tables II and VI. It must be borne in mind, however, that the actual layout in the field is not nearly so regular as that shown in these diagrams, since many of the plots have to be staggered out of line, owing to gaps and irregularities in the tree population.

Method of Recording Yields.—In laying out an experiment, each tree is allotted an index number, and its yield in the number of pods at a picking is recorded. In addition, the weight of wet cacao obtained from each plot of 18 trees is measured. The final records of yield for each crop can therefore be expressed either (a) as number of pods, or (b) as weight of wet cacao.

General Considerations.—Cursory inspection of the yields obtained during the first crop after the application of the manures reveals the fact that, at three of the sites, namely Torrecilla, Las Hermanas and River Estate, there has been an appreciable increase in yield from the treated

Table I.

Sites of Phosphate Manurial Experiments; Composition of Top six-inch Layer of Soil.

Soil Type and Locality.	Sand %	Index of Texture (I.T.)	Reaction		O.M. %	N. %	C/N Ratio.	Rate of Soln.	Avail. K ₂ O (p.p.m.)	Avail. P ₂ O ₅ (p.p.m.)
			Norm. (pH)	Exch. (pH)						
<i>Torrecilla.</i>										
(1) Sandy Alluvium, Northern Range, Trinidad.	53.7	23	6.7	6.2	1.80	0.16	6.5	—	150	21
<i>Las Hermanas.</i>										
(2) Clay Alluvium, Caroni Plain, Trinidad.	9.4	47	6.2	5.4	2.99	0.27	6.0	201	139	29
<i>River Estate.</i>										
(3) Alluvial Fine Silt, Northern Range, Trinidad.	4.6	35	6.0	5.3	2.39	0.19	7.3	38	56	15
<i>Sta. Serviera.</i>										
(4) Brasso Clay, Central Range, Trinidad.	13.5	40	6.3	5.5	2.14	0.23	5.4	150	114	79
<i>Carriere.</i>										
(6) Red earth, derived from augite andesite, Grenada	28.8	38	8.1	7.7	3.21	0.26	7.3	160	245	17

plots. At the other three sites, the manure was not applied until August, 1932, and one would not expect any response during the 1932-33 crop from these three experiments. It is proposed therefore in the ensuing discussion to consider in detail only the yields of the Torrecilla, Las Hermanas and River Estate experiments for the 1932-33 crop. All the experiments are being continued, and, when records from two or three successive crops have been obtained, more definite conclusions may be reached with regard to the success of these manurial experiments at the different sites.

(II) Las Hermanas.

The experimental block is situated on flat ground about 250 yards from the right bank of the Caroni River. The soil is a fairly heavy-textured alluvial clay, and is typical of that of the cacao vegas of the Caroni Plain. The chief physical and chemical characters of the top six inches of soil are shown in Table I. The fertility of the soil is relatively low, and the cacao trees are in poor condition. The average age of the cultivation is approximately 30 years. The area is subject to occasional attacks of Thrips, and has suffered in this respect during 1932 and 1933. Thrips attacks have probably contributed largely to the great variation in yield obtained from individual plots receiving the same treatment.

Results.—The total yields obtained from the differently treated plots are shown in Tables II and III.

Table II.

Las Hermanas Phosphate Experiment; Individual Plot Yields.

Number of Pods and weight of Wet Cacao (lb.)

	A	D	B	C
No.	355	293	266	163
Wt.	80	72	55	37
	C	A	D	B
No.	312	498	299	169
Wt.	70	114	68	39
	B	C	A	D
No.	198	369	334	231
Wt.	50	81	69	47
	D	B	C	A
No.	273	156	305	244
Wt.	60	31	68	49

Treatments. Lb. Superphosphate per tree.

A ..	..	3 lb.
B ..	..	0 "
C ..	..	1 "
D ..	..	2 "

Table III.

Las Hermanas Phosphate Experiment; Total Yields.

Treatment lb. Superphosphate per tree.	No. of Pods.	Per cent. Increase over Control.	Wt. of wet cacao (lb.)	Per cent. Increase over Control.
3 lb.	1,431	81.4%	312	78.3%
2 lb.	1,096	38.9	247	41.2
1 lb.	1,149	45.6	256	46.3
Control	789	—	175	—

These results indicate that the plots treated with superphosphate have given a very marked increase in yield over the control plots, the increase in yield from trees receiving an application of three pounds per tree being about 80 per cent.

Statistical Analysis of Yield Data.

Use has been made of Fisher's method of analysis of variance (4) in order to reduce to a minimum the effects of soil and plot variation. The analysis is shown in Tables IV and V.

Table IV.

Las Hermanas: Analysis of Variance of Yields in Number of Pods.

Due to	Degrees of Freedom.	Sum of Squares.	Variance.	Loge.	$\frac{1}{2}$ Loge.
Total ..	15	118,203	—	—	—
Rows ..	3	11,766	3,922	—	—
Columns	3	35,927	11,976	—	—
Treatments	3	51,911	17,304	9.8678	4.9339
Error ..	6	18,599	3,098	8.2158	4.1079

Reading from Table of Z ($P=.05$) = 0.7798. Calculated value of Z = 0.8260.

Differences between Totals, in order to be statistically significant must exceed $\sqrt{2 \times 3098 \times 4 \times 2.447} = 386$ pods.

Table V.

Las Hermanas: Analysis of Variance of Yields in Weight of Wet Cacao.

Due to	Degrees of Freedom.	Sum of Squares.	Variance.	Loge.	$\frac{1}{2}$ Loge.
Total ..	15	6,380	—	—	—
Rows ..	3	869	289	—	—
Columns	3	2,141	714	—	—
Treatments	3	2,373	791	6.6733	3.3367
Error ..	6	997	166	5.1120	2.5560

Reading from Table of Z ($P=.05$) = 0.7798. Calculated value of Z = 0.7807.

Differences between Totals, in order to be statistically significant must exceed $\sqrt{2 \times 166 \times 4 \times 2.447} = 89.2$ lb. wet cacao.

From these results, the following conclusions may be drawn :—

(i) The increase in yield due to an application of three pounds of superphosphate per tree might be due to chance less than once in one hundred times, and is therefore definitely significant.

(ii) Marked increases in yield (41 and 46 per cent.) are shown by plots receiving two pounds per tree and one pound per tree, but, owing to the great variability in yield of individual plots these increases might be due to chance more than once in twenty times, and therefore can scarcely be considered statistically significant. These conclusions hold good whether yield is considered as number of pods, or as weight of wet cacao.

(iii) There is no indication that the application of superphosphate has exerted any effect in increasing the average weight of wet cacao contained in the individual pods produced by the treated and the untreated trees, so that the beneficial effect of the fertiliser in this area apparently has been confined solely to an increase in the number of pods brought to maturity, and has not influenced the size of the individual pods.

(III) Torrecilla.

The experimental block is situated at a well-sheltered site on flat ground about 150 yards from the left bank of the Arima River, and just above the level of flood water. The soil is a sandy loam, in which gravel is encountered at comparatively shallow depths. It is similar in type to that occurring in many of the Northern Range vegas. The chief physical and chemical characters of the top six inches of soil are shown in Table I. The cacao trees are well grown, some being from 25 to 30 feet high. The average age of the trees is probably about 50 to 60 years. The area is subject to occasional severe attacks of Thrips, such an attack occurring in November, 1932.

Results.—The total yields from the differently-treated plots are shown in Tables VI and VII.

Table VI.

Torrecilla Phosphate Experiment; Individual Plot Yields.

Number of Pods and Weight of Wet Cacao (lb.)

	D	A	C	B
No.	499	404	436	280
Wt.	92	91	92	47
	B	D	A	C
No.	378	441	492	421
Wt.	77	106	100	87
	C	B	D	A
No.	211	301	385	379
Wt.	44	64	88	82
	A	C	B	D
No.	321	411	313	545
Wt.	57	75	59	97

Treatments. Lb. Superphosphate per tree.

A	..	..	3 lb.
B	..	..	0 ..
C	..	..	1 ..
D	..	..	2 ..

The results indicate that the plots treated with superphosphate manure have given a very marked increase in yield over the control plots. When yields are considered in terms of weight of wet cacao, increases appear to be greater than when yields are considered in terms of number of pods. This suggests that the treated plots have not only produced a greater number of pods, but have also produced larger pods than the control plots. This apparent increase in size of pod due to manuring is also shown in Table VII.

Table VII.

Torrecilla Phosphate Experiment; Total Yields.

Treatment ; lb. Superphosphate per tree.	No. of Pods.	Per cent. Increase over Control.	Weight of wet cacao (lb.)	Per cent. Increase over Control.	No. of pods per lb. wet cacao (size of pod).	Per cent. Increase over Control.
3 lb.	1,596	25.5%	330	29.8	4.84	6.7%
2 lb.	1,870	47.0	383	55.1	4.88	5.7
1 lb.	1,509	18.6	298	20.6	5.06	1.5
Control	1,272	—	247	—	5.15	—

Statistical Analysis of Yield Data.—The analysis of variance of (a) weight of wet cacao, (b) number of pods and (c) size of pod, are shown in Tables VIII, IX and X.

Table VIII.

Torrecilla: Analysis of Variance of Yields in Weight of Wet Cacao.

Due to	Degrees of Freedom.	Sum of Squares.	Variance.	Log _e .	$\frac{1}{2}$ Log _e .
Total ..	15	5,506	—	—	—
Rows ..	3	1,293	431	—	—
Columns	3	762	254	—	—
Treat-ment	3	2,441	814	6.7020	3.3510
Error ..	6	1,010	168	5.1240	2.5620

Reading from Table of Z ($P=.05$) = 0.7798. Calculated value of Z = 0.7890.

Differences between Totals, in order to be statistically significant, must exceed $\sqrt{2 \times 168 \times 4 \times 2.447} = 89.7$ lb. wet cacao.

Table IX.

Torrecilla: Analysis of Variance of Yields in Number of Pods.

Due to	Degrees of Freedom.	Sum of Squares.	Variance.	Log _e .	$\frac{1}{2}$ Log _e .
Total ..	15	117,827	—	—	—
Rows ..	3	29,330	9,777	—	—
Columns	3	8,028	2,616	—	—
Treat-ments	3	45,735	15,245	9.6343	4.8171
Error ..	6	34,734	5,789	8.6638	4.3319

Reading from Table of Z ($P=.05$) = 0.7798. Calculated value of Z = 0.4852 (*i.e.* calculated value of Z less than observed value; therefore differences in yields due to treatments are not significant).

Table X.

Torrecilla: Analysis of Variance in Size of Pod.

Due to	Degrees of Freedom.	Sum of Squares.	Variance.	Log _e .	$\frac{1}{2}$ Log _e .
Total ..	15	44,888	—	—	—
Rows ..	3	24,310	8,103	—	—
Columns	3	6,714	2,238	—	—
Treat-ment	3	2,844	948	—	—
Error ..	6	11,020	1,837	—	—

Treatment variance is less than error variance; therefore differences in size of pod due to treatments are not significant.

From these results, the following conclusions may be drawn:—

(i) The plots treated with superphosphate have yielded a larger number of pods than the control plots, but the variability in yield between individual plots has been so large that the differences in yield of pods between the manured plots and the control plots cannot be considered to be statistically significant.

(ii) When yields are considered as weight of wet cacao, the increase in yield (55.1 per cent.) due to an application of two pounds of superphosphate per tree might be due to chance less than once in one hundred times; this increase is therefore very definitely significant.

(iii) Increase in yield (29.8 and 20.6 per cent.) have been obtained from plots receiving applications of three pounds of superphosphate per tree and one pound per tree respectively. These increases, however, might be due to chance more than once in twenty times, and cannot therefore be considered statistically significant.

(iv) There is an indication that the plots treated with superphosphate manure have produced pods of larger average size than the control plots, and it would appear therefore that the application of superphosphate manure in this area has resulted, not only in an increase in the number of pods brought to maturity, but also in an increase in size of pods. It cannot be shown at present that the difference in pod size is statistically significant, and it must be left to results obtained in succeeding years to provide a more definite answer to this question.

The results obtained in this experiment have clearly demonstrated the necessity of recording yields both as number of pods and as weight of wet cacao. The indication here obtained of an increase in the size of pod (*i.e.* weight of wet cacao per pod) may have an important bearing on the question of the effect of phosphate manuring on *quality of cacao*, since records obtained by Pound (5) have shown a close relationship between weight of wet cacao per pod and size of bean, which is an index to quality. The importance of recording yields as both weight of wet cacao and number of pods, lies not only in the fact that weight of cacao is a more exact measure of quantitative yield, but by recording both units, we may obtain preliminary information on the effect of manuring in improving quality as shown by an increased size of bean.

(IV) Torrecilla and Las Hermanas; Combined Results.

The experiments laid down at each of these sites, have shown that plots treated with different dressings of superphosphate manure gave marked increases in yield, even during the first crop after treatment. When the yields from the individual plots are considered separately, it has been shown that the differences between certain of the treatments are not sufficiently large to allow mathematical proof of their significance. This is

due to the great variation in yield of individual plots, so that, with only four replicates of each treatment, very large differences in total yield are necessary before statistical significance can be demonstrated. When, however, the yield data from the two experiments are combined, the number of replicates of each treatment is increased to eight, and an error variance based on twelve degrees of freedom instead of six is thus obtained. By this means, therefore, we are much more likely to obtain mathematical proof of the significance of the differences due to treatment.

Results.—Weight of wet cacao is considered to be a more important unit of yield than number of pods, and in comparing the combined records only, the yield in weight of wet cacao alone has been considered. The analysis of variance for the combined yields from the two experiments is set out in Table XI.

Table XI.

Torrecilla-Las Hermanas Phosphate Experiments ; Combined Analysis of Variance of Yields in Weight of Wet Cacao.

Due to	Degrees of Freedom.	Sum of Squares.	Variance.	Loge.	$\frac{1}{2}$ Loge.
Total ..	31	14,268	—	—	—
Rows ..	6	2,162	360	—	—
Columns	6	2,903	484	—	—
Squares	1	2,382	2,382	—	—
Inter-action	3	839	279	—	—
Treatments	3	3,974	1,325	7.1891	3.5945
Error ..	12	2,008	167	5.1180	2.5590

Reading from Table of Z ($P=.01$) = 0.8919. Calculated value of Z = 1.0355.

Differences between Totals, in order to be statistically significant must exceed $\sqrt{2 \times 167 \times 8 \times 2.179} = 112.6$ lb. of wet cacao.

Conclusions from these results are as follows:—

(i) The increases in yield due to treatments of three pounds per tree and two pounds per tree might be due to chance less than once in one hundred times. These increases therefore are very definitely significant.

(ii) The increase in yield due to treatment of one pound per tree might be due to chance less than once in twenty times. This increase is also definitely significant.

(iii) There is a significant difference in yield between the two experimental blocks. The Torrecilla block gives a much higher yield, probably due to more fertile soil and better environmental conditions.

Table XII.

Torrecilla-Las Hermanas combined ; Total Yields in lb. of Wet Cacao.

Treatment.	Las Hermanas.	Torrecilla.	Treatment Totals.
A (3) ..	312	330	642
B (0) ..	175	247	422
C (1) ..	256	298	554
D (2) ..	247	383	630
Total of Squares	990	1,258	—

By combining the yield data from these two experimental blocks it has been possible to show that, during the 1932-1933 crop, significant increases in yield have been obtained from applications of superphosphate of 3 lb. per tree, 2 lb. per tree and 1 lb. per tree (equivalent to 900 lb., 600 lb. and 300 lb. per acre). These percentage increases in yield are as follows:—

3 lb. per tree .. 52.1 per cent.

2 lb. per tree .. 49.3 do.

1 lb. per tree .. 31.3 do.

The heavier applications of 3 and 2 lb. per tree have given approximately the same yields. The heavier applications show a considerable increase (about 15 per cent.) over the application of 1 lb. per tree: this increase is not however statistically significant.

(V) River Estate.

The experimental block at River Estate is situated on flat land in the Diego Martin Valley. The trees form part of a former distance-planting experiment laid down in 1913 by the Trinidad Department of Agriculture, and are uniform in age (20 years). In this respect, the experiment differs from the other two experiments already described. The soil is a fairly close-textured alluvial silt; its chief physical and chemical characters for the top six inch layer of soil are shown in Table I. The original lay-out adopted by the Department of Agriculture in this case was a 3×3 Latin square, since the available area was too small to contain a 4×4 square.

Results.—The total yields obtained from the differently treated plots are shown in Table XIII.

Table XIII.

River Estate Phosphate Experiment ; Individual Plot Yields.

Number of Pods.

Experimental Year, 1933.

Average Previous
4 Years, 1932-29.

A 400	B 189	C 225	A 354	B 264	C 290
B 180	C 411	A 227	B 288	C 341	A 355
C 289	A 363	B 127	C 305	A 389	B 151

Treatments.

A. 3 lb. superphosphate per tree

B. 0 lb. do.

C. $1\frac{1}{2}$ lb. do.

No manurial treatments previous to 1933.

These results show that the plots treated with superphosphate manure appear to have given a very marked increase in yield over the control plots. For this experiment there are yield records available for four years previous to the experimental year. The average yields for the different plots for these four years is shown in Table XIV.

Table XIV.

River Estate Phosphate Experiment; Total Yields in Number of Pods.

Manured, 1933.			Unmanured (1929-32).	
AFTER MANURING.			NATURAL YIELDS.	
Treatment lb. Super- phosphate per tree.	No. of Pods.	Per cent. Increase over Control	No. of Pods.	Per cent. Increase over Control.
3 lb.	990	99.7	1,098	56.2
1½ lb.	925	86.4	936	33.1
Control	496	—	703	—

Although the yield results show that, by a peculiar coincidence, the plots receiving superphosphate manure have a considerably higher *natural* yield than the control plots, the corrected yields for the experimental year show that there has been an increase in yield due to phosphate manuring of nearly 45 per cent.

Statistical Analysis of Yield Data.—The yield figures of this experiment have been examined by the analysis of variance, the yields of the experimental year being corrected by means of previous records, according to the method of Sanders (6). The results are presented in Tables XV, XVI, XVII, XVIII.

Table XV.

River Estate Analysis of Variance; Experimental Year 1933.

Due to	Degrees of Free- dom.	Sum of Squares.	Vari- ance.	Loge.	½ Loge.
Total ..	8	84,735	—	—	—
Rows ..	2	307	—	—	—
Columns	2	27,047	—	—	—
Treat- ment	2	48,034	24,017	10.0860	5.0433
Error ..	2	9,347	4,673	8.4496	4.2248

Calculated $Z=0.8185$.

Table XVI.

River Estate Analysis of Variance; Average Yield 1929-1932.

Due to	Degrees of Free- dom.	Sum of Squares.	Vari- ance.	Loge.	½ Loge.
Total ..	8	39,157	—	—	—
Rows ..	2	3,230	—	—	—
Columns	2	7,135	—	—	—
Treat- ment	2	26,284	13,142	9.4833	4.7417
Error ..	2	2,508	1,254	7.1341	3.5671

Reading from Table of Z ($P=.05$) = 1.4722.
Calculated $Z=1.1746$.

Table XVII.

River Estate; Analysis of Co-Variance.

Due to	Degrees of Freedom.	SXY.	Co-Variance.
Total ..	8	44,639	—
Rows ..	2	881	—
Columns	2	13,804	—
Treatment	2	33,957	16,978
Error ..	2	—4,003	—2,002

Table XVIII.

River Estate; Final Analysis of Variance $b(y-bx)$, i.e. for 1933 Yields, corrected by Average Yield 1929-1932.

Due to	Degrees of Free- dom.	Sum of Squares.	Vari- ance.	Loge.	½ Loge.
Total ..	7	327,822	—	—	—
Rows ..	2	11,395	—	—	—
Columns	2	89,485	—	—	—
Treat- ment	2	223,983	111,991	11.6262	5.8131
Error ..	1	2,959	2,959	7.9929	3.9964

Reading from Table of Z ($P=.05$) = 2.6479.
Calculated value of $Z=1.8167$.

Table XVII presents the final analysis of variance of the experimental year yields, corrected for previous records; the figures show that the increases in yield obtained from the manured plots cannot be considered statistically significant. At first sight, these results obtained by the statistical analysis of these records are disappointing, but, in reality, we may be justified in concluding that we have indeed obtained a real increase in yield due to manuring. The large percentage increase due to manure is distinctly suggestive, although it is impossible to show mathematical proof of the

significance of the differences. The lack of statistical significance is attributed largely to the original type of layout adopted (namely, a 3 × 3 Latin square), which is quite unsuited for carrying out a manurial experiment on a crop such as cacao. With only three replicates of each treatment, and an error variance based on only two degrees of freedom, yield increases of well over 100 per cent. would be necessary before we could expect to obtain statistical proof of their significance. Furthermore, this layout is particularly unsuitable for the use of previous records by Sanders' method. When the error variance obtained by the final analysis of the corrected yields (Table XVIII) is compared with the error variance obtained by simple analysis of the experimental yields (Table XV), it will be seen that we have apparently obtained an increase in precision of 1.58 due to the use of previous records. This increase in precision is offset by the fact that, in calculating the regression coefficient from the yields in previous years, one degree of freedom due to error is used up, and therefore, in the final analysis, the variance due to error is based on only one degree of freedom, and hence it is practically impossible to obtain a significant value for *Z*. The results of this experiment have served a very useful purpose in that they have clearly indicated the drawbacks of a single small Latin square as a type of field layout for manurial experiments on cacao.

(VI) Costings.

A detailed statement of costs would be out of place at this preliminary stage of the experiments, but it is of interest to present some figures to show that the experiments are being conducted within sound economic limits. In Table XIX a comparison is made between the costs of the various applications of superphosphate and the values of the increases in crop obtained at Las Hermanas and Torrecilla Estates.

These figures show that, with the price of cacao at the low figure of four cents per pound, the only increase which shows a margin of profit is that due to an application of 1 lb. per tree (300 lb. per acre). With prices at five cents per pound,

the increase due to an application of 2 lb. per tree (600 lb. per acre) also shows a margin of profit, but not as great as that due to the application of 1 lb. per tree. With prices at seven cents per pound and over, the greatest margin of profit is shown by the application of 2 lb. per tree. These figures indicate that, from an economic point of view, the maximum application of superphosphate for the cacao crop is 2 lb. per tree or 600 lb. per acre. Increases in yield obtained by heavier applications than this are not large enough to balance the increased cost of the manure. It must be stressed again that these figures are only of a preliminary nature, but they do indicate that the most economic rate of application of superphosphate manure on cacao probably lies between 1 and 2 lb. per tree (300-600 lb. per acre), depending on the market price of cacao at the time.

(VII) Discussion.

The manurial experiments designed to test the effect of different dressings of superphosphate manure on the yield of cacao have so far yielded extremely promising results. During the first crop after the application of the manures, increases in yield of the order of 50 per cent. have been obtained from the treated plots. In addition to the marked response to phosphatic manuring which has thus been demonstrated, these preliminary results are of great value in that they provide useful information concerning the technique of laying out and supervising manurial experiments on cacao. This information is particularly valuable at the present time in view of the additional series of experiments which are now contemplated to test out other findings based on cacao soil surveys described in Part I of this report.

In the first place, with regard to the actual laying out and selection of experimental sites in the field, it is of vital importance for a crop such as cacao in Trinidad, that the actual laying out of field experiments should be carefully supervised. Not only should the site of the experiment be carefully chosen, but the individual plots should be selected so as to avoid obvious patches of either very good or very bad cultivation. This will

Table XIX.

Las Hermanas and Torrecilla Costs.

Cost of Superphosphate compared with Value of Increased Crop.

SUPERPHOSPHATE.		INCREASE IN YIELD PER ACRE.		VALUE OF INCREASE AT DIFFERENT PRICES.				
Application per tree.	Cost per acre.	Wet Cacao lb.	Dry Cacao lb.	4 cents per lb.	5 cents per lb.	6 cents per lb.	7 cents per lb.	10 cents per lb.
3 lb.	\$ 12 00	458	183	\$ 7 32	\$ 9 15	\$ 10 98	\$ 12 81	\$ 18 30
2 lb.	8 00	432	173	6 92	8 65	10 38	12 11	17 30
1 lb.	4 00	275	110	4 40	5 50	6 60	7 70	11 00

often necessitate the plots being staggered out of line, and will sometimes result in a very irregular formation of the "square". In the opinion of the writer, a large amount of the great variation in natural yield within a particular area may be eliminated by this careful preliminary selection by eye in the field.

The results obtained at Torrecilla Estate have shown the importance of recording the weight of wet cacao from each plot in addition to counting the number of pods from each tree, since, by recording both these units of yield, the effect of the manure on the average size of pod, as well as on the number of pods brought to maturity, can be accurately measured.

With regard to the statistical treatment of yield records, the results obtained at Torrecilla and Las Hermanas are of especial interest. When each of these two experimental blocks was considered separately, although marked increases in yield were obtained from the smaller applications of manure, it was not possible for either block to demonstrate statistically the full significance of these increases. When the records from the two blocks were combined, mathematical proof of the significance of these differences was easily obtained. At Las Hermanas alone, a 50 per cent. increase in yield was necessary in order to be significant, while at Torrecilla a 37 per cent. increase was required. When the two sets of yield records were combined, the increase required to show statistical significance was only 27 per cent. At River Estate, the results obtained have shown that a 3×3 Latin square layout is quite unsuited for manurial experiments on cacao, especially if the use of previous records for increasing the precision of the experiment is contemplated. With this type of layout, it may therefore not be possible to demonstrate the significance of increases of less than 100 per cent. Even the 4×4 Latin square has serious limitations where previous records are not available, and the results obtained during this first year of the experiments show that if this type of layout is to be used in Trinidad cacao fields, two squares should be laid down in order that increases of 25 to 30 per cent. in yield may be conclusively demonstrated. If only one 4×4 square is used on ordinary cultivation which is heterogeneous for age, increases of 50 per cent. may be necessary before one can hope to show statistical proof of their significance. Where a sufficiently large area of uniform cacao cultivation can be found, a 5×5 Latin square would obviously be preferable to a 4×4 square, but it is probable that the layout of two 4×4 squares would be easier from a practical point of view than the layout of one 5×5 square, even though the total area covered by the two smaller squares be the larger. Cheesman and Pound (3) have already referred to

this method of increasing the precision of experiments, and have pointed out the practical limitations imposed by the amount of land taken up, and by the unwieldiness of large experiments. They have suggested, as an alternative method of increasing precision, the use of previous records by Sanders' method (5). This method unfortunately has the limitation that, after laying out the experiment, two or three years must elapse before any results can be obtained. In endeavouring to increase the precision of manurial experiments on cacao, the experimenter must obviously be guided in his choice of methods by the relative importance of space required for the layout and of the time interval required before the experimental results become available.

(VIII) Summary.

(i) The manurial experiments described in this paper are based on information obtained from recent cacao soil surveys. The interdependence of soil survey work and field manurial experiments on perennial tropical crops is stressed.

(ii) Results are presented for three different field experiments designed to test the response of the cacao tree to superphosphate manure on different soil types in Trinidad.

(iii) During the first year after the application of superphosphate manure, increases in yield of the order of 50 per cent. have been obtained from the treated plots.

(iv) The yield data have been subjected to statistical analysis, and have provided useful information concerning the technique of laying out manurial experiments on cacao.

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PART III.

A STUDY OF THE RELATIONSHIP BETWEEN NUTRIENT SUPPLY AND THE CHEMICAL COMPOSITION OF THE CACAO TREE.

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(I) Introduction.

As an outcome of recent soil surveys conducted by the Department of Chemistry at the Imperial College of Tropical Agriculture, the conclusion has been reached that there is an apparent lack of balance in the nutrient status of many of the low-yielding cacao soils of the British West Indies. During recent years, a large number of investigations have been initiated to determine the rôle of the principal nutrient elements concerned in plant growth, and many experiments have been made to determine the optimum amounts and proportions of the different elements needed by different plant species. Although most of these investigations have concerned temperate crop plants, perhaps some of the more important findings may be directly applicable to tropical crops, such as cacao. It may be of interest, therefore, to present a brief review of the present state of knowledge with regard to mineral plant nutrition, and to indicate how far modern ideas of nutrient balance may be applied to problems concerning the growth and manuring of the cacao tree.

(II) The Role of the Principal Nutrient Elements in Plant Nutrition.

Cultivated plants under ordinary field conditions are affected to a far greater extent by changes in the nitrogen, phosphorus and potassium content of the soil, than by that of any other element essential to plant growth. In the ensuing discussion therefore, the nutrient status of the soil with regard to these three elements only will be considered.

(a) *Nitrogen*.—It has been demonstrated that abundant supplies of nitrogen cause rapid vegetative development, but increased leaf growth may not necessarily be accompanied by greater assimilation of carbohydrate. Another effect of large nitrogen supply is to retard ripening, since vegetative activities are continued for a longer period, and fruiting consequently is delayed. Excessive supplies of nitrogen lead to the development of large, dark-green leaves, which are frequently soft and sappy, and particularly subject to insect and fungus attack. Russell (1) points out that crops grown for the sake of their vegetative portions are greatly improved by increased nitrate supply, but, with regard to fruit trees, excess of nitrogen may result in too much leaf growth and too little fruiting, as well as in many other harmful physiological effects. Hence the manurial requirements of contrasted tropical crops, such as sugar-cane and cacao, will be fundamentally different.

The foliar symptoms associated with nitrogen deficiency in fruit trees have been described by Wallace (2), (3), (9), (10). Nitrogen starvation is

characterised by stunted growth, delay in the times of opening of flowers and leaf buds, and reduction of the number of flowers, owing to the death of lateral buds. The amount of foliage developed is scanty, and eventually the trees carry foliage only at the tips of the branches, and thus develop a characteristic bare wood appearance. The leaves are small and yellowish-green in colour, and may later develop reddish tints. The amount of fruit formed is small in quantity, due to the suppression of lateral buds. The root systems are poorly developed, and consist almost entirely of fine fibrous rootlets.

(b) *Potassium*.—Potassium exerts several different effects on the growing plant. Wallace (4), (9) has shown that potassium deficiency in fruit trees tends to promote internal "physiological drought," especially when environmental conditions are conducive to desiccation. He has shown that potassium deficiency is a factor contributing to leaf scorch of fruit trees, which is a pathological condition induced by unsatisfactory water relations. Mann (13) has further shown that the potassium content of leaves exerts a controlling influence on the rate of transpiration under conditions of high temperature and bright sunshine. It would thus appear that potassium is a factor concerned in controlling both the uptake and the loss of water by the plant, and that plants adequately supplied with potassium are more resistant to wide fluctuations in water supply (14).

Numerous recent investigations have demonstrated further that potassium partly determines the efficiency of the leaf as an assimilator of carbon dioxide in the synthesis of carbohydrate (15), (17), (18), (19), (20). In this respect, however, contradictory results have been obtained for different plants. Thus, Gregory (17) showed that the leaves of barley, insufficiently supplied with potassium, contained little carbohydrate, whilst Nightingale (18) found considerable quantities of carbohydrate in potassium-deficient tomato leaves. Nightingale (18) has shown, however, that the increased quantity of carbohydrate in potassium-deficient tomato leaves is not due to increased assimilation, but rather to a retardation of the processes of reduction of nitrate and the formation of protein. In potash-starved plants, nitrate is not reduced, and therefore protein is not formed and sugars are not consumed, but tend to accumulate in the leaf. Gregory (15), (17) has shown that potassium compounds are essential for cell division in growing plants, and that they tend to accumulate in the meristematic tissues or actively-growing portions of the plant.

The above-mentioned investigations indicate that potassium exerts a marked effect on the utilisation of nitrogen by the plant, both directly, through its effect on protein formation, and indirectly, through its effect on the rate of assimilation of carbohydrate. Russell (1) has summarised the relationship between potassium and nitrogen supply as follows:—"The effects of potassium starvation on the growing plant fall into two groups, according to the supply of nitrogen. With small supplies of nitrogen, the leaves are small and little carbohydrate is synthesized, but its proportion to the nitrogen compounds in the plant, which are also small, is not abnormal. The plant is stunted and rather ashy-grey in colour, its leaves tending to die prematurely. Otherwise, the plant shows no striking abnormality, until fruit or seeding time, when both fruit and seed tend to be small in quantity, in size and in weight. With large supplies of nitrogen, on the other hand, the uptake of nitrogen is considerable; the leaves are large but relatively inefficient owing to lack of potassium, and therefore produce less carbohydrates in proportion to their nitrogen compounds. There results, therefore, an abnormal excess of nitrogen in the plant, which leads to various undesirable effects. Potassium is thus the counterpart of nitrogen which is associated with the size of the leaf; the two nutrients are intimately linked in their action. It is well recognised in practice that neither potassic nor nitrogenous fertiliser gives its full effect without adequate supplies of the other."

Wallace (2), (3), (9), (10) has described the visible effects of potassium deficiency on fruit trees. With regard to foliar symptoms, there is a marginal browning of the leaf which may extend inwards between the veins as far as the mid-rib. The brownish-grey colour of the leaves gives them the appearance of having been scorched by fire. At a later stage, the leaves become bronze or copper coloured. Potassium deficiency also leads to die-back of vegetative shoots, and to the production of a greatly increased number of flower buds. Fruit yields are greatly reduced, for, although a large number of fruits are set, the fruits formed are very liable to shedding, and those which eventually mature are small and shrivelled.

(c) *Phosphorus*.—An abundant phosphate supply has been shown to be particularly necessary for plants in the early stages of growth (21), (22). Brenchley (21) has demonstrated by means of water culture experiments that barley, during the first six weeks of its life, absorbs sufficient phosphate for full normal growth. When phosphate is withheld during the early stages of growth, the plant is irreparably damaged, no matter how much phosphorus is given later. The importance of an adequate nutrient supply during the early stages of growth of elements other than phosphorus has also been stressed. When plants are provided with an adequate and balanced nutrient supply during their early growth stages, they are better

able to withstand adverse conditions in later life, and are able to utilise the less-readily available nutrients in the soil. Phosphate has a marked effect on the development of the root systems of plants. Thus, phosphatic fertilisers are considered particularly valuable on heavy clay soils where roots do not naturally grow vigorously, but they are less needed on sandy soils, because abundant root growth normally occurs on these soils. Russell (1) states that the ill-defined properties associated with quality seem to increase with the phosphate content of the crop. Lyon (23) has shown that phosphorus may act as an accessory accelerator of respiration, while Thomas (43) has found that applications of phosphate to apple trees results in an increased utilisation of starch. Barrenscheen and Pany (24) have also produced evidence to show that phosphate is concerned in the intermediate stages of carbohydrate metabolism in plants, and Eidelman (25) has demonstrated that phosphate absorption increases with increase in light duration during each twenty-four hour period. Eidelman also showed that high phosphate content of the plant is coincident with greatest photosynthetic activity at average day length and at relatively high temperatures. It would appear, therefore, that phosphate, as well as potassium, is concerned in the manufacture and utilisation of carbohydrate by the plant.

Wallace (2), (3), (9) (10) has demonstrated the effects of phosphorus starvation on English fruit trees. The leaves exhibit characteristic purple and bronze tints over their entire surfaces, the tinting often being accompanied by brownish spots. The amount of foliage and the size of individual leaves are small, and eventually the only leaves developed are the terminal rosettes. The times of opening of flower and leaf buds are appreciably delayed. Flower formation is greatly restricted owing to the death of lateral buds, and the flowers formed are stunted. The quantitative yield of fruit is greatly reduced, owing to the suppression of lateral buds. Wallace emphasizes the fact that most of these features are similar to those due to nitrogen deficiency. With regard to quality of fruit, phosphorus-starved fruits differ markedly from nitrogen-starved fruits. Their colour is dull, with a suggestion of the bronzing which develops so markedly on the leaves, and their commercial qualities are wholly undesirable. The root systems of phosphorus-deficient trees are small in size, but they differ markedly in character from those produced by nitrogen deficiency, consisting almost entirely of coarse roots, almost entirely devoid of fine fibrous rootlets.

(d) *Possible Application to Problems Concerning the Growth of the Cacao Tree*.—It is a matter of conjecture how far the findings of Wallace and others with regard to temperate fruit trees may be applied to the cacao tree. Wallace's investigations demonstrate that certain symptoms and habits of growth are associated with deficiencies of particular elements, and they indicate lines along which researches concerning the nutrition of the cacao

tree may be directed. They have shown that fruit trees exhibit markedly different growth characteristics with regard to flowering and setting of fruit, depending upon whether potassium is deficient or whether nitrogen or phosphate is deficient. In cases of nitrogen or phosphate deficiency, relatively few flowers and fruits are produced, but in the case of potassium deficiency, large numbers of flowers are produced, and large numbers of fruits are set, though a great proportion is subsequently lost by shedding. Such a condition is analogous to the frequently-observed behaviour of the cacao tree, which flowers profusely and sets large numbers of fruits, but usually a considerable proportion of the young fruits shrivels on the trees and fails to mature. The behaviour of the cacao tree may be partially determined by potassium supply, either through its direct effect on the metabolism of the plant, or indirectly through its effect on the assimilation of carbohydrate and the utilisation of nitrogen. This explanation is purely speculative however, since no direct supporting evidence has yet been accumulated. Wallace's findings are based on observations of trees growing in carefully-controlled sand cultures; the problem is more involved when the trees are growing under normal field conditions. The factors operating in the soil are more numerous and complex, owing to the differences which various plant species exhibit in their ability to obtain particular elements from the same soil, and in their requirements of different elements necessary for satisfactory growth. The available evidence indeed suggests that deficiency of a particular element in the soil may not simply result in symptoms of deficiencies of that element in the plant. For instance it has been shown that, where phosphate is deficient, the plant may be unable to obtain adequate supplies of potash (26), and, in such a case, symptoms of potash deficiency may appear in the plant, and the employment of phosphatic manure might cause a disappearance of those symptoms (16). Furthermore, deficiency of one element may prevent the plant making full use of a second element, even if present in the soil in abundance, and absorbed in adequate quantity. Such a close relationship appears particularly to exist between nitrogen and potassium.

The uptake of available nutrient elements by the plant is largely governed by the ratio in which these elements are present in the soil, so that the growth effects of a particular element do not necessarily depend solely on its gross deficiency or abundance. The effects vary, depending on the proportion of the other elements present in the soil. Thus it is not only the absolute amounts of different elements present in the soil that may control plant growth, but also the *proportionate* amount of one to the other.

(III) The Concept of Physiological Balance with respect to Soil Nutrients and Manures.

The idea of physiological balance in plant nutrition, first put forward by Loeb in 1908 (27), has inspired a large amount of research during

recent years. Although many quantitative experiments have been made in order to ascertain the best amounts and proportions of the different elements required for plant growth, no definite laws, generally applicable under all conditions, have yet been formulated.

Previous to Loeb, certain theories concerning nutrient balance and the absorption of mineral substances by plants, were advanced by Liebig (28) who held that, "by the deficiency or absence of one necessary constituent, all others being present, the soil is rendered barren to all those crops to the life of which that one constituent is indispensable." This is known as Liebig's "Law of the Minimum," from which it was deduced that deficiency of one particular nutrient element in the soil results in a decreased absorption by the plant of all other elements. Actual observations, however, were not always in agreement with Liebig's hypothesis, and later, Liebscher (29) suggested the substitution of his "Law of the Optimum," which states that "the plant is able to utilise to a greater extent that growth factor present in minimum amount, when the other factors already present approach their optimum values." A few years later, Mitscherlich (30) stated another law which maintains that any one individual growth factor can independently contribute to increased utilisation of other growth factors, provided it is not itself present in optimum concentration.

No direct experimental evidence opposed to Liebig's law of the minimum was forthcoming, however, until Lagatu and Maume, of L'Ecole Nationale d'Agriculture de Montpellier, showed that the actual course of absorption of nitrogen, phosphorus and potassium may be irreconcilable with Liebig's views. Their investigations (31), (32), (33), (34), (35), (36), (37), (38) were based upon the analysis of the leaves of grape vines from experimental plots treated with complete manure (nitrogen, phosphate and potash), and with combinations in which one of each of these elements was absent. They demonstrated the following important facts:—(i) The application of an incomplete manure, deficient in one of the three elements, results in an increased absorption by the plant of the other two elements. (ii) The plant absorbs from a soil treated with an incomplete manure less of the missing element than it does from a soil containing no addition of manure. (iii) The application of an unbalanced manure results in decreased yield, not due to decreased absorption of the added elements, but to a nutritional lack of balance in the plant arising from increased absorption of the added elements.

These results indicate the difficulties involved in attempts to explain the comparative chemical composition of different individuals of the same plant species, unless the results are referred to some standard control material. The standard for comparison should be a plant of the same species growing under conditions of balanced nutrition which yield the most satisfactory growth and reproduction.

Lagatu and Maume claim that their results demonstrate that deductions based on Liebig's law of the minimum are not capable of general application. Later experiments carried out by Thomas and Anthony (39), (44) in the United States of America, on the other hand, gave results which are apparently quite in accordance with Liebig's hypothesis. Omission of any one of the elements, nitrogen, phosphorus or potassium, from a manurial treatment, resulted in decreased absorption of the remaining elements, and was accompanied by decreased growth and reproduction. Other experiments carried out in Austria by Sekera (45) gave various results which differed materially, depending on the identity of the nutrient element which was omitted from the manurial treatment. These Austrian experiments were carried out with barley on a soil which showed a high content of potassium but low contents of nitrogen and phosphorus. Omission of potassium resulted in an increased absorption of phosphorus and nitrogen, but reduction in nitrogen resulted in a decreased absorption of potassium and phosphorus. In this particular case, the addition of nitrogen and phosphorus resulted in balanced nutrition, and led to their increased absorption. On the other hand, field experiments conducted by Wallace showed that, although the omission of potassium from a manure applied to a soil deficient in that element resulted in increased absorption of nitrogen and phosphorus, when phosphorus or nitrogen was omitted there was a decreased absorption of the other two added elements in accordance with Liebig's law.

Thomas (40), (41), (42) has recently reviewed the general question of physiological balance in plant nutrition, and has suggested that the omission of one nutrient element from a manurial mixture will result either in an increased absorption, or in a decreased absorption of the remaining two elements, depending on the inherent nutrient supplying-ability of the soil, or level of nutrition, particularly with respect to the supply of the omitted elements. He has defined an optimum manurial ratio as follows:—

"The optimum ratio of the constituents of a fertiliser may be defined as that ratio which on the addition of any one of its nutrient constituents—nitrogen, phosphorus or potassium—results in no increased utilisation by the plant of any of the other elements."

A great deal of the experimental evidence is conflicting and it is doubtful whether, at the present state of knowledge, any definite generalisations can be put forward which are widely applicable under different conditions of soil and environment. It is apparent, however, that there exists for each plant species a physiologically-balanced nutrient solution from which normal absorption occurs, and greatest growth and yield result. A departure from this balance, either through deficiency or excess, will produce a disturbance of the absorption relations, and may exert profound effects on metabolism. Thus, the simple determination of nutrient deficiencies of a

soil is not alone sufficient for the purpose of estimating manurial requirements. Excess, as well as deficiency, of a particular element may give rise to physiological disturbances which may result in decreased growth and yields. Hence, haphazard manurial treatments may sometimes be actually harmful, since they may give rise to an unbalanced nutrient supply to the plant.

(IV) The Luxury Consumption of Nutrients.

The evidence which has accumulated from various investigations indicates that plants may absorb nutrients in approximately the same proportion that they are present in the nutrient medium, especially in the early stages of growth. Accordingly, if a particular element is present in the soil in excess of the amount required for physiological balance, that element may be absorbed by the plant in excess of its requirements. This "luxury consumption" may result in a disturbance of normal metabolism, which may seriously affect growth and yield, but to an extent depending partly on the identity of the particular element that is absorbed in excess. Thus, in the case of coffee, Camargo (46) has recently demonstrated by controlled pot culture and field experiments, that the nutrient element which most markedly influences the development of roots, stems and leaves is phosphorus. In excess, it is not harmful, a characteristic not shared by nitrogen and potash, which may not be added arbitrarily without risk of disturbing normal growth. The addition of excess of potassium above a certain limit to coffee cultures containing a constant supply of nitrogen, produces a marked decrease in yield. Furthermore, when the potassium supply is constant, and the nitrogen supply is diminished, a decrease in yield also follows. The two factors, nitrogen and potassium thus seem to be interdependent. Wallace (2), (3), (4), (9), (10) has emphasized the significance of the potassium/nitrogen ratio in the growth of fruit trees. Leaf scorch of fruit trees, insufficiently supplied with potassium, in sand cultures increases with each increment of nitrogen in the nutrient solution. Bronzing of the leaves of citrus trees growing in nutrient solutions having a low potassium/nitrogen ratio has also been reported by Reed and Haas (47). The close interrelationship between nitrogen and potassium has been stressed by Russell (1), who has indicated that, although excessive absorption of nitrogen may increase the susceptibility of plants to disease, this condition is alleviated by supplying potassic manures.

According to these various facts, the problem of balanced plant nutrition may be considered from two entirely different points of view by the practical agriculturist. Firstly, a soil may be markedly *deficient* with respects to a particular nutrient element. In this case, harmful effects on plant growth may follow, either because of a limited uptake of other essential elements, or because of their increased uptake, depending on the initial general level of fertility of the soil.

Secondly, a soil may contain a marked *excess* of a particular element, in which case harmful effects may result because of its absorption in excess of the plant's requirements. The elements nitrogen and potassium appear to be peculiarly related in this connection; the presence of either in excess usually profoundly disturbs normal plant metabolism and depresses yields. On the other hand, phosphorus may be present and may be absorbed even in great excess without noticeably affecting plant processes.

(V) The Balance between Nitrogen and Carbohydrate in the Plant and its possible Relationship with Supply of Mineral Nutrients.

No discussion of balanced plant nutrition would be complete without reference to the carbohydrate/nitrogen ratio, and its effects on the growth responses of the plant. It has been shown, recently by plant physiologists (48), (49), (50) that growth and reproduction in plants depends to a considerable extent on the relative proportion of carbohydrate and nitrogen occurring within the plant. When the value of the carbohydrate/nitrogen ratio is relatively small, vegetative activities seem to follow, but when the value is relatively large, reproduction apparently takes place. If the carbohydrate/nitrogen ratio attains a very high value (due to abundant carbohydrate and scarcity of nitrogen), reproductive as well as vegetative activities may cease altogether. Recently this relationship has been firmly established, and it is already accepted in most countries, though its precise application in the management of fruit trees in order to control their fruitfulness is still obscure. With regard to tropical crops such as cacao and citrus, the manner in which the carbohydrate/nitrogen ratio may be influenced by pruning or by nitrogenous manuring has been indicated by Cheesman (51).

The relative amounts of carbohydrate and nitrogen present in the plant cell sap depend very largely on the activities of the leaves and roots respectively. Carbohydrate is essentially a product of leaf manufacture. On the other hand, nitrogenous substances gain access to the plant through the roots, soluble nitrogenous compounds (nitrates and ammonium) being absorbed by the root hairs from solution in water.

The amount of carbohydrate manufactured by leaves is controlled by more than one factor, but, since its synthesis depends on the influence of light on chlorophyll, the intensity of light may be the chief factor deciding carbohydrate formation. The supply of mineral nutrients may also influence the rate of assimilation of carbohydrate by the plant. Thus it has been demonstrated that potassium may have a marked controlling effect on the formation of carbohydrate in the leaf (15), (17), (18), (19), (20). In this connection Russell (1) states that "the effect of potassium in correcting the harmful action of excess of nitrogen, is in part at any rate attributable to its effect in increasing the net production of sugar and starch in the leaf,

thus restoring to more normal values the carbohydrate/nitrogen ratio which has been disturbed by excessive supply of nitrogen." It would appear, therefore, that the delicate balance between potassium and nitrogen, to a certain extent, is connected with the balance between carbohydrate and nitrogen in the plant. Phosphate has been shown also to be concerned in the manufacture and utilisation of carbohydrate (23), (24), (25), (43), and it is apparent that the production of carbohydrate by the plant must be greatly influenced by supplies of all three chief nutrients, though particularly by potassium, which markedly affects the efficiency of the leaf as an assimilating organ.

The amount of nitrogen taken up by the plant depends partly on the ability of the soil to supply nitrogen, and partly on soil moisture. If soil water is deficient, smaller amounts of the nitrogenous compounds in the soil are dissolved, and smaller quantities are absorbed by the root. In this connection, Taylor (52) has recently drawn attention to the fundamental differences in manurial practices in the fruit orchards of England and of the United States of America. In North America, where summer rainfall is small and light intensity is high, it appears that the leaves are able to store up vast quantities of carbohydrate, and in consequence, fruit trees would be expected to respond to large dressings of nitrogenous manure. Actually this has been found to be the case (53). The application to the soil of quickly-available forms of nitrogen has given more beneficial results than any other fertiliser treatment in the growing of deciduous fruits, whereas many tests have failed to demonstrate general response to the application of potassic manures. On the other hand, in England, trees growing in a soil well supplied with summer moisture, and exposed to light of lower intensity, are more likely to exhibit greater root activity in absorbing nitrogenous substances, and to manufacture relatively less amounts of carbohydrate. Such trees, therefore, are more likely to respond to potash manures than to nitrogenous manures alone. Wallace (9), (10), (12) at Long Ashton, has demonstrated that this is indeed the case. He concludes that "potassium deficiency is the most serious deficiency disease of fruit trees in the country, and has been of extremely frequent occurrence in the past". Wallace also points out that potassium deficiency must usually be considered in relation to nitrogen supply. The relative proportions of nitrogen and potassium necessary for balanced nutrition of crop plants, to a certain extent are evidently influenced by weather conditions, as well as by the nutrient-supplying ability of the soil.

How far these principles may be applied to a crop such as cacao growing under tropical conditions of high rainfall and high light intensity is still problematical, but the results of investigations conducted with other fruit trees at any rate imply that correct manurial practices may be

influenced by factors other than soil conditions alone. Possibly different levels of nitrogen nutrition are required for cacao, depending on the degree of shading, and thus fundamental differences may exist in the manurial ratios required for greatest growth and yield in contrasted areas such as Grenada and Trinidad, where cacao is grown without shade and with heavy shade respectively. Under West Indian climatic conditions, considerable differences in the duration of bright sunshine occur from one year to another. Thus, during 1933 in Trinidad, there were nearly 300 hours less bright sunshine than during 1930.

(VI) The Chemical Analysis of Plant Tissues as a Possible Means of determining the Nutrient Supplying Ability of the Soil.

In order to determine the ratio between the nutrient constituents of an added manure needed to provide a balanced soil solution, a knowledge of the nutrient supplying ability of the soil with respects to the different elements, is obviously essential. Many investigations have been carried out in the past with the object of evolving laboratory tests for assessing the nutrient status of the soil. Certain of the suggested methods have been found capable of useful application, but they are still more or less empirical, and are not based on precise knowledge of the availability to plants of the various forms of nitrogen, phosphorus and potassium present in the soil. Different plants possibly have different requirements with regard to nutrient supply. A particular level and balance of nutrients may be suitable for one plant but unsuitable for another. A full discussion of the chemical methods at present in vogue for the direct determination of available plant nutrients is outside the scope of this paper, but it may be stated that the Truog test (54) for available soil phosphate, which has been used for some years by the Soil Science Department of the College, has been found by many workers (55), (56), to show good agreement with the results obtained by pot tests and field experiments. With regard to potassium, it is generally conceded that replaceable or exchangeable potassium is the best index of available soil potassium, but it cannot be claimed that any satisfactory method has yet been evolved for determining the exact status of nitrogen in the soil. Even the chemical methods at present in use for the estimation of available soil phosphate and potassium do not provide a reliable measure of the precise quantities of these elements available to the plant; they merely give information as to whether the soil is abundantly, moderately or poorly provided with phosphate and potassium.

Because of the unreliability of simple chemical methods as a means of measuring the availability of nutrient elements in the soil, a number of biological tests that make a direct appeal to the plant have recently been devised, prominent among which are the methods elaborated by Mitscherlich and by Neubauer. With regard to phosphate, a simple pot test has been specifically

devised for estimating its availability in which use is made of the peculiar sensitivity of the tomato plant to phosphate deficiency (57). In view of the fact that phosphate is particularly important to plants during the early stages of growth, the test can be completed in three or four weeks. An important aspect of the future work of the agricultural chemist evidently concerns the elaboration of satisfactory methods for determining nutrient substances in the soil actually available to the plant. The greatest promise of success seems to lie in the employment of the plant itself as an indicator of its own nutrient requirements.

Experiments carried out in the past to elucidate problems of physiological balance in plant nutrition have depended mainly on the supposed value of chemical analysis of plant tissues as a means of tracing the absorption of different elements. Recently a number of workers (58), (59) have endeavoured further to adopt this method for diagnosing the nutrient requirements of soils. For instance, the Neubauer pot test depends entirely upon the chemical analysis of young seedlings. In England, Wallace (2), (7), (8) has reinvestigated the possibility of applying chemical analysis of certain portions of the plant as a means of diagnosing the nutrient requirement of fruit trees. By a number of pot experiments he has established the fact that deficiencies of nitrogen, potassium, calcium, magnesium and phosphorus are indicated in various portions of the trees by relatively small contents of the respective elements in comparison with the amounts present in adequately nourished trees, and by their effects on the proportionate amounts of other elements. The most definite results have been obtained by the chemical analysis of plants growing in carefully controlled sand and water cultures, but it is problematical how far similar methods can be used successfully for diagnosing nutrient requirements in the field. Wallace (5), (6), (11) has shown, however, that chemical analysis of plant tissues provides a ready means of distinguishing in the field between cases of chlorosis of plums due to potassium deficiency and due to iron deficiency respectively. In a field experiment on gooseberry bushes (7), which had been growing under various manurial treatments for six seasons, it was demonstrated that deficiency of potassium was clearly reflected in the chemical composition of leaves, stems and berries. Deficiency of phosphorus, on the other hand, affected the chemical composition of the different portions of the plant only when potassium had been adequately supplied. When potassium was deficient (as in the case of the no manure plots) the phosphate content of the leaves was in all cases high, which showed that deficiency of potassium resulted in an increased uptake of phosphate. The chemical analysis of plant tissues may thus furnish evidence of deficiency of an element only when that element has become the primary limiting factor to growth. It appears that, for each crop plant, a standard of comparison is necessary in order correctly to interpret the

results of detailed chemical analysis. A suitable standard is provided by the chemical composition of plants of the same species growing under conditions of balanced nutrition which result in greatest growth and yield.

(VII) The Relationship between the Chemical Composition of the Cacao Tree and Nutrient Supply.

With regard to the cacao tree, the applicability and value of plant chemical analysis as a means of assessing its nutrient relationships have not yet been completely explored. Essential requirements are carefully controlled field manurial experiments and sand or water cultures, which will provide material for comparative examination. A series of sand cultures has recently been started under the Cacao Research Scheme, and field experiments are available in which manures have been supplied for two seasons. Preliminary work has already been completed on the chemical composition of cacao leaf material of different ages, and grown under widely different environmental conditions. The results so far obtained have shown that leaves of different ages, and leaves collected from contrasted good and bad environments exhibit marked differences in chemical composition. It has also been demonstrated that cacao trees subject to the attack of Thrips show a high nitrogen/potassium ratio in their leaves.

During the past year, the chemical composition of leaves taken from cacao trees receiving different manurial treatments has been determined in the laboratory. The material for examination was obtained from two manurial experiments which were laid down to test the effect of different dressings of superphosphate manure on the yield of cacao. At one of these sites (Torrecilla Estate), marked increases in yield due to phosphate manuring have been obtained. At the other site (Santa Serviera Estate), no increase in yield has yet been shown by the manured plots. At both

sites, the experimental layout (a 4×4 Latin square) and the manurial treatments are the same. In addition to the phosphate treatments, half of each plot has received a dressing of two pounds of potassium sulphate per tree, so that the effects of phosphate manuring with and without potash can be estimated. Both these experiments were designed on the assumption that soil nitrogen is relatively abundant at each site, a supposition which is based on evidence obtained from recent soil surveys. The results of the soil survey work which led to the initiation of these manurial experiments, and the yield responses so far obtained, have been described in Parts I and II of this report.

(VIII) Method of Sampling and Type of Material examined.

The preliminary investigations already reported showed that differences in composition of leaf material taken from contrasted environments were more clearly reflected by young leaves than by mature leaves. In the present investigation, therefore, material was selected from the young terminal shoots during the second or third week after the beginning of a "growth flush", when the leaves were just hardening and turning green. A suitable number of leaves was carefully selected from each tree in the differently treated plots. Total dry matter, content of ash and of nitrogen, phosphate, and potash were determined on the samples in the laboratory by the analytical staff of the College Chemistry Department. As an aid to the interpretation of the analytical results, comparison has been made between the composition of leaves from the experimental plots, and the composition of leaves of cacao trees growing in a soil of known high natural fertility. In each instance, the chemical composition of leaves from these high yielding trees has been taken as a standard for comparison. Since the cacao trees examined have been subjected to differential manurial treatments for a short time only, and since the number of

Table I.

Santa Serviera Estate ; Composition of Dry Matter of Young Leaves from Cacao Trees receiving Different Manurial Treatments.

Superphosphate Treatment.	Superphosphate only.				Superphosphate+Potash, 2 lb. K_2SO_4 per tree.				Dry Matter in Fresh Material. per cent.	
	Ash %	N %	P_2O_5 %	K_2O %	Ash %	N %	P_2O_5 %	K_2O %	No Potash.	Potash.
Control	7.81	2.44	0.607	2.80	7.90	2.38	0.583	2.83	31.6	31.3
1 lb. per tree ..	7.21	2.24	0.615	2.47	7.48	2.48	0.705	2.94	31.3	31.8
2 lb. per tree ..	7.92	2.41	0.647	2.55	7.01	2.52	0.682	2.72	32.4	30.7
3 lb. per tree ..	7.49	2.41	0.685	2.50	7.23	2.52	0.732	2.56	31.3	30.5
Standard Good Plot	9.90	2.35	0.500	2.64	—	—	—	—	—	—

determinations so far carried out is small, the conclusions so far reached must be regarded merely as tentative. No attempt has been made to interpret the results by statistical methods.

(IX) Results : (1) Santa Serviera Estate.

At this experimental site, there has been no indication of any increase in yield due to the application of phosphate or potash manures. Detailed examination of the soil has revealed that its texture and physical condition are not well suited to the growth of cacao, and that it contains a harmful concentration of sulphate (due to accumulated gypsum) at comparatively shallow depths. Chemical tests have further shown that the soil is moderately well supplied with available phosphate and potash.

The results of leaf analysis set out in Tables I and II (Santa Serviera Estate) indicate a marked increase in the amount of phosphate present in the leaves of trees that have received phosphate manure. Applications of potash manure, in addition to phosphate, have resulted in a further increase in the phosphate content of the leaves. Nevertheless, comparison of the relative proportions of the different elements present in the leaves shows that the application of phosphatic manures has not resulted in any improvement in nutrient balance. The increased uptake of phosphate would therefore appear to be a luxury consumption, since the nitrogen/phosphate and the potash/phosphate ratios have been displaced further from the standard values by the several manurial treatments.

The relative proportions of the different elements in the leaves from plots receiving potash only but no phosphate shows a slightly closer approach to the standard values, and the application of potash together with phosphate, has resulted, in an increased concentration in the leaf of all three elements, nitrogen, phosphorus and potassium, indicating that, at this site, potash may be deficient rather than phosphate. The results obtained, however, are by no means definite, but

when they are considered together with the lack of response in yield, it would appear that unbalanced nutrient supply is not the chief factor limiting growth and yield at this site. Any shortcomings in nutrient level or nutrient balance, with respects to phosphate or potash, are apparently masked by other factors, such as unsuitable physical condition of the soil, and the possible harmful effects due to the presence of gypsum in the subsoil.

(X) Results : (2) Torrecilla Estate.

At this experimental site, a very marked increase in yield has resulted from the application of phosphatic manures. Since a full crop has not yet been reaped subsequent to the application of the potash manures, no data are available concerning the yield responses of the trees to potash. Chemical analysis has shown that the soil contains a very small amount of available phosphate, and a moderately high content of available potash.

The data presented in Tables III and IV (Torrecilla Estate) indicate that the leaves taken from plots receiving superphosphate alone possess a higher content of both phosphate and potash than the control plots. Leaves taken from plots receiving potash in addition to phosphate possess a higher content of potash, but the phosphate content is approximately the same as that of leaves from the control plots. Where potash alone was applied, no increase in the potash content of the leaf has occurred, but, where potash and phosphate were applied together, a marked increase has occurred in the potash content of the leaf, but a decrease in phosphate content. It would appear, therefore, that at this site, the application of superphosphate manure has resulted in an increased uptake of potash by the cacao tree. Comparing the nutrient ratio values obtained for the standard good plants with those obtained for the control plot material receiving no manurial treatment, it is apparent that a very marked difference is exhibited by the relative amounts of nitrogen and of potash contained in the leaves

Table II.

Santa Serviera Estate ; Composition of Ash of Leaves from Cacao Trees receiving Different Manurial Treatments.

Superphosphate Treatment.	Superphosphate Only.						Superphosphate + Potash, 2 lb. K ₂ SO ₄ per tree.					
	N %	P ₂ O ₅ %	K ₂ O %	N P ₂ O ₅	K ₂ O P ₂ O ₅	N K ₂ O	N %	P ₂ O ₅ %	K ₂ O %	N P ₂ O ₅	K ₂ O P ₂ O ₅	N K ₂ O
Control ..	31.3	7.77	35.9	4.03	4.62	0.87	30.3	7.38	35.8	4.11	4.85	0.86
1 lb. per tree ..	31.0	8.53	34.2	3.63	4.01	0.91	33.2	9.43	39.3	3.52	4.17	0.85
2 lb. per tree ..	30.4	8.17	32.2	3.72	3.94	0.94	36.0	9.73	38.8	3.70	3.99	0.93
3 lb. per tree ..	32.1	9.14	33.3	3.51	3.64	0.96	36.9	10.12	35.4	3.45	3.50	0.99
Standard Good Plot	23.9	5.10	26.6	4.66	5.21	0.89	—	—	—	—	—	—

from the two plots. The value of the nitrogen/potash ratio of the leaf for the standard plot is 0.89 and for the experiment control plots, 1.36. *The effect of adding superphosphate alone has been to increase the uptake of potash*, thus narrowing the nitrogen/potash ratio, so that it approximates closer to the standard value. Taking the relative proportions of nitrogen, phosphorus and potassium present in the leaves from the standard plot as an index of a well-balanced nutrient status, it would seem that a state of markedly unbalanced nutrition exists in the control plots of this experiment, and that the application of phosphate alone has partly restored the balance. A moderately heavy application of two pounds of superphosphate per tree appears the most effectively to have brought the balance nearer to the standard. On the other hand, the heavier application of three pounds of superphosphate per tree appears to have been excessive, since it has displaced the nutrient ratio values further from the standard. The greatest increase in yield was obtained from plots receiving two pounds of superphosphate per tree, and this coincides with the dressing which has most favourably affected the nutrient ratios in the leaves.

The addition of potash alone has resulted in a slight narrowing of the nitrogen/potassium ratio, not due to an increased potash content of the leaf, but due to a decreased nitrogen content. Addition of potash alone, however, has not resulted in any improvement in the nutrient balance, for, though the nitrogen/potassium ratio has been slightly improved, the nitrogen/phosphate ratio and the potash/phosphate ratio have been displaced further from the standard values. Finally, the addition of potash together with phosphate in all cases has resulted in a marked improvement of the nutrient balance as shown by the chemical composition of the leaf, so that it would appear that *an application of superphosphate of three pounds per tree is not excessive so long as potash also is supplied.*

As a practical interpretation of these results, it may be claimed that chemical analysis of young leaves has shown that the cacao trees at the Torrecilla site are suffering from an unbalanced nutrient supply as compared with standard good conditions. Phosphate in particular appears to be deficient, since the addition of phosphate alone has resulted in a marked improvement in the nutrient balance as indicated by the chemical

Table III.

Torrecilla Estate ; Composition of Dry Matter of Young Leaves from Cacao Trees receiving Different Manurial Treatments.

Superphosphate Treatment.	Superphosphate Only.				Superphosphate+Potash 2 lb. K ₂ SO per tree.				Dry Matter in Fresh Material per cent.	
	Ash %	N %	P ₂ O ₅ %	K ₂ O %	Ash %	N %	P ₂ O ₅ %	K ₂ O %	Super Only.	Super- Potash.
Control ..	7.96	2.24	0.504	1.65	9.03	2.21	0.609	1.74	37.8	38.1
1 lb. per tree ..	7.23	2.00	0.617	2.04	8.12	2.07	0.565	2.05	35.0	35.8
2 lb. per tree ..	7.58	2.21	0.574	2.33	8.57	2.25	0.579	2.31	35.6	37.2
3 lb. per tree ..	7.48	2.17	0.585	1.87	8.15	2.34	0.521	2.37	34.3	36.7
Standard Good Plot	9.90	2.35	0.500	2.64	—	—	—	—	—	—

Table IV.

Torrecilla Estate ; Composition of Ash of Leaves from Cacao Trees receiving Different Manurial Treatments.

Superphosphate Treatment.	Superphosphate Only.							Superphosphate+Potash 2 lb. K ₂ SO ₄ per tree.						
	N %	P ₂ O ₅ %	K ₂ O %	N P ₂ O ₅	K ₂ O P ₂ O ₅	N K ₂ O		N %	P ₂ O ₅ %	K ₂ O %	N P ₂ O ₅	K ₂ O P ₂ O ₅	N K ₂ O	
Control ..	28.1	6.33	20.7	4.44	3.27	1.36		24.4	6.77	19.3	3.60	2.85	1.26	
1 lb. per tree ..	27.7	8.58	28.3	3.23	3.30	0.98		25.4	6.96	25.2	3.65	3.62	1.01	
2 lb. per tree ..	29.2	7.58	30.7	3.85	4.05	0.95		26.1	6.75	27.0	3.87	4.00	0.97	
3 lb. per tree ..	29.1	7.80	25.1	3.73	3.22	1.16		27.0	6.02	27.4	4.49	4.55	0.99	
Standard Good Plot	23.9	5.10	26.6	4.66	5.21	0.89		—	—	—	—	—	—	

composition of the leaf. Nevertheless, applications of superphosphate at a rate heavier than two pounds per tree (600 pounds per acre) apparently are detrimental. The heavier application of superphosphate alone seems to have resulted in a luxury consumption of phosphate, as revealed by a high content of phosphate in the leaf. The applications of potash together with phosphate has resulted in a *decreased* uptake of phosphate and a displacement of the nitrogen/phosphate and potash/phosphate ratios closer to the standard values, indicating an improvement in nutrient balance. At this site, therefore, the cacao trees apparently fail to obtain adequate supplies of potassium when phosphate is deficient, since the most marked effect of supplying phosphate has been to increase the content of potassium in the leaf. Addition of potash alone has apparently resulted in no improvement in the nutrient balance, but the application of heavier doses of phosphate in addition to potash has resulted in a definite improvement. Superphosphate, applied at the rate of three pounds per tree (900 pounds per acre) does not appear therefore to be excessive at this site so long as potash is also supplied.

(XI) General Discussion of Results.

The results of the chemical analysis of young cacao leaves collected from plots receiving different manurial treatments, may be interpreted in the light of modern theories concerning physiological balance in plant nutrition, as follows. A standard of comparison has been selected, the standard being the chemical composition of cacao leaves taken from high-yielding trees growing on a soil of known high natural fertility. These trees have given large yields continuously over a long period of time without any applications of fertiliser, and soil analysis has demonstrated relatively high contents of available phosphate and available potash. It is probable, therefore, that the balance and level of soil nutrient supply lie near the optimum, and the chemical composition of leaves taken from these cacao trees may be taken as a standard composition, resulting from a satisfactorily balanced nutrition. The composition of leaves taken from trees receiving different manurial treatments has been compared with the standard. If a manurial treatment has altered the chemical composition of the leaf so that the proportionate amounts of the different elements approach closer to the standard values, then it is concluded that the particular manurial treatment has resulted in an improved balance in the supply of mineral nutrients. In the present investigation, an examination has been made of the chemical composition of cacao leaves taken from two different sites where manurial experiments are being conducted. Both these field experiments were designed to test the effect on the yield of cacao of superphosphate manure, with and without potash. The different applications of superphosphate have now been applied for two seasons, but the half-plot potash treatment has been applied once only. At one of the sites (Torrecilla Estate),

a marked increase in yield due to phosphate manuring has been obtained; at the other site (Santa Serviera Estate) no increase in yield has yet been recorded.

At Santa Serviera Estate, the application of phosphate has resulted in an increased phosphate content of the leaf, but the ratios of the different elements present in the leaf have not been displaced nearer to the standard values. The ratios most closely approximating to the standard values have been obtained for plots receiving potash only; hence potash is apparently deficient at this site rather than phosphate. On the other hand, factors other than nutrient supply may more satisfactorily explain the extremely poor condition and low yields of the cacao trees at this site.

At Torrecilla Estate, the application of phosphate manure appears to have resulted in an increased uptake of potassium by the tree, and in a more balanced nutrient supply, as shown by the relative proportions of the different elements present in the leaves. Very heavy applications of phosphate (900 pounds per acre) have apparently resulted in unbalanced nutrition and luxury consumption of phosphate, except when potash also is applied. The most striking result obtained at this site is that applications of phosphate alone appear to have caused an increased uptake of potassium, and a narrower nitrogen/potassium ratio in the leaf. This finding may be of the utmost importance at the present stage of our investigations, for previous experiments conducted at Torrecilla have proved that a high ratio of nitrogen to potassium in the leaves renders the cacao tree particularly susceptible to Thrips attack. Accordingly, it was concluded that any practice which tends to lower the nitrogen/potassium ratio of the leaf would be beneficial, and the application of potassic manures was specifically recommended. In the light of these later results, however, it appears that potash manures may produce no beneficial effects when phosphate is deficient, and applications of *phosphatic manures alone* may be effective in that they narrow the nitrogen/potassium ratio in the leaf. A wide nitrogen/potassium ratio may therefore furnish a reliable index of soil phosphate deficiency at the particular level of nutrition existing at this site.

In view of the fact that the different manurial experiments described above have only recently been initiated, the results so far obtained are necessarily merely preliminary in nature, and no definite pronouncements can yet be made concerning the general effects of nutrient supply on the chemical composition of cacao leaves. Nevertheless, these results are promising in-so-far as they indicate that chemical analyses of cacao leaves (and possibly of other parts of the tree) may form a valuable aid in diagnosing soil nutrient deficiencies and manurial requirements of cacao soils. In order that further progress may be made in this investigation, a definite series of carefully-controlled field manurial experiments, laid down at a number of different sites, is obviously essential,

so that the effect of nutrient supply on the chemical composition of the cacao tree may be studied under various normal field conditions. Sand cultures, in which nutrient supply can be, more strictly and more easily controlled, should also yield valuable information on this problem.

(XII) Summary.

(i) The relationship between the chemical composition of cacao leaves and the supply of mineral nutrients has been investigated.

(ii) Recent critical investigations concerning the mineral nutrition of plants have been reviewed and discussed. The application of modern ideas concerning physiological balance in plant nutrition to problems involved in the growth and manuring of cacao has been indicated.

(iii) Chemical analyses of cacao leaves taken from a manurial experiment (Torrecilla Estate), have shown that the chemical composition of the leaf may be appreciably altered by fertiliser treatments. Application of phosphatic manures resulted in increasing the proportion of potash to nitrogen in the leaf.

(iv) Application of potash alone did not have such a marked effect on the relative proportion of nitrogen and potassium in the leaf.

(v) From these results, it would appear that, at this site, the cacao tree is unable to obtain adequate supplies of potassium when phosphate is deficient.

(vi) This finding may have an important bearing on the problem of Thrips attack on cacao, since previous investigations have shown that cacao trees possessing a high ratio of nitrogen to potassium in the leaf are particularly susceptible to attack.

(vii) The chemical composition of leaves from cacao trees treated with superphosphate approaches much more closely to the standard optimum values than the composition of leaves from control plots. This indicates that, at this site, phosphate manuring has resulted in a more balanced nutrient supply.

(viii) Very heavy applications of superphosphate (900 pounds per acre) appear to have resulted in unbalanced nutrition, unless potash also is applied.

(ix) This finding coincides with the yield responses obtained from this manurial trial. It was here demonstrated that the greatest increase in yield was obtained from a moderately heavy dressing of superphosphate, equal to 600 pounds per acre.

(x) At another site (Santa Serviera Estate) the application of superphosphate manure has resulted in a marked increase in the amount of phosphate in the leaf.

(xi) At this site, the composition of cacao leaves from plots receiving different applications of superphosphate diverges more widely from the standard optimum values than does the composition of leaves from the control plots. Hence it has been concluded that the increased uptake of phosphate may be a luxury consumption.

(xii) This finding coincides with the yield responses so far obtained from this manurial experiment, where no increases in yield due to phosphate manuring have yet been recorded.

(xiii) The value and the possible significance of these experimental results has been indicated. In view of the limited number of determinations so far carried out, the importance of further investigations under different conditions of soil and nutrient supply has been stressed.

(XIII) Acknowledgment.

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PART IV.

A CRITICAL EXAMINATION OF METHODS OF MEASURING ATMOSPHERIC HUMIDITY AND RATE OF EVAPORATION IN ECOLOGICAL STUDIES.

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(I) Introduction.

The ecological studies of environmental moisture conditions in cacao fields, which have been carried out in Trinidad since the beginning of 1931, have yielded considerable data concerning the relationship between rainfall, soil moisture, relative humidity and evaporating ability of the atmosphere. From a consideration of these data, it has been possible to demonstrate (1), (2), striking relationships between fluctuations in environmental moisture conditions and the behaviour of the cacao tree with regard to vegetative flushing, flowering and setting of fruit. Rainfall data alone gave only an inadequate representation of these fluctuations; records of relative humidity and of evaporating ability of the air were found to be essential for their accurate interpretation. By such means, marked differences in the moisture environment of two contrasted “good” and “bad” cacao plots were demonstrated. The most striking difference was revealed by the evaporating ability of the air at different levels above the ground, and thus valuable information was obtained concerning the function of shade and shelter in cacao fields.

The satisfactory measurement of atmospheric moisture conditions is an ecological question of the greatest importance in connection with problems concerning the growth of tropical crops, and it will be of interest at this juncture to examine the available meteorological data in order to determine the best methods of measuring atmospheric moisture conditions. The data available for examination are mainly based on continuous records obtained at the two contrasted cacao plots by means of Negretti and Zambra recording hair hygrometers (relative humidity) and Livingston atmometers (rate of evaporation). In addition, other, more extensive, data are available at the College Meteorological Station. The equipment here includes wet and dry bulb thermometers, a

cup anemometer (for measuring wind velocity) and a Campbell-Stokes sunshine recorder, as well as a recording hair hygrometer and a set of Livingston atmometers.

(II) Types of Instruments and Methods of Observation.

(a) *Wet and Dry Bulb Thermometers*; readings taken at 8 a.m. and 4 p.m. daily.—These well-known and widely-used hygrometers have the advantages of simplicity and cheapness, but readings recorded only once or twice daily probably afford a very inadequate indication of the humidity of the atmosphere within periods of twenty-four hours duration.

(b) *Negretti and Zambra Recording Hair Hygrometer*.—This instrument gives a direct continuous recording of relative humidity without reference to tables, and the data obtained provide a reliable measure of the humidity of the atmosphere during a particular period. Recording hair hygrometers, however, have a number of disadvantages when used in ecological studies; they are expensive and delicate instruments, and require frequent adjustment and calibration. Fortunately, in Trinidad, a constant check on the hair hygrometer is afforded by the fact that nearly every night throughout the year the humidity of the atmosphere rises to saturation point and dew is deposited. The humidity record during the night, therefore, consists of a horizontal line at or near 100 per cent. relative humidity. Dade (3) has used this method in the Gold Coast for calibrating Edney recording hygrometers which he used to investigate the atmospheric humidity of cacao fields in relation to the incidence of pod disease.

(c) *Livingston Atmometers*.—These instruments are designed and produced by Dr. Burton E. Livingston of the Johns Hopkins University, Baltimore, U.S.A. They measure the evaporating ability of the air as affected by temperature,

humidity, wind velocity and radiation from the sun and sky. Atmometers are of two types, the black bulb atmometer (which measures rate of evaporation due to all these causes) and the white bulb atmometer (which is only slightly sensitive to the influence of radiation); the difference between the readings of the black and the white bulb atmometers should therefore give a measure of the evaporation due to the effects of radiation alone. Atmometers consist essentially of standardised porous porcelain spheres, 5 cm. in diameter, having a small cylindrical neck, to which a glass tube is attached by means of a rubber stopper. Each sphere is filled with distilled water, and is connected by means of the supply tube to a reservoir. Atmospheric pressure on the water in the reservoir keeps the tube and sphere cavity filled during the time that evaporation from the external porcelain surface proceeds. The atmometers are generally set up in batteries of six (three black and three white), so that, if one fails to function properly, it can easily be detected and replaced. Livingston atmometers are claimed to be far more sensitive to small differences in low wind velocities than any other climatological instrument, except perhaps the wet bulb thermometer, with which it is difficult, however, to secure a satisfactory integration for a period of fluctuating air movement. The length of time between readings of the atmometers may be varied to suit the purpose of the investigation. In well sheltered environments, atmometers can be left unattended for as long as two weeks, provided they are furnished with sufficiently large reservoirs of water. The instruments require careful supervision; if left unattended for any length of time, the bulbs quickly become dirty and clogged. In this respect, the black bulbs are more troublesome than the white, since the white bulbs can be kept clean by periodic scrubbing with a tooth-brush. A dilute solution of formalin, poured over the bulbs at definite intervals, is effective in preventing the growth of moulds and algae. A pamphlet giving complete information concerning the use and care of atmometers has been prepared by Dr. Livingston, and is usually included with each consignment of atmometer bulbs supplied.

(d) *Measurements of Wind Velocity and Hours of Sunshine.* These records are obtained from a standard type of cup anemometer and a Campbell-Stokes sunshine recorder respectively. Descriptions of these instruments are usually contained in catalogues of meteorological instruments.

(III) Methods of Examination of the Available Data.

For the purpose of determining the relationships between various meteorological factors, records of daily fluctuations might be expected to yield more information than mean records of weekly or monthly fluctuations. The employment of mean values of long-period fluctuations is undesirable, in that it obscures the significance of extreme variations likely to occur in the individual factors.

Thus, wind velocity in Trinidad increases considerably during the dry season, whilst atmospheric humidity decreases, so that both factors tend to increase evaporation during this period. On the other hand, during any one day, wind velocity may attain a high value whilst humidity may also increase, and so diminish the evaporating effects of the rapidly moving air. Thus, the more usual comparative effects of wind velocity and of humidity on evaporation can best be gauged by an analysis of the daily records. Accordingly, daily records obtained at the College Meteorological Station by different methods and instruments have been compared over a period of thirty-five days, extending from 2nd January to 5th February, 1933. At this time of year in Trinidad, the change over from the wet to the dry season occurs, and extreme fluctuations in the various meteorological factors take place from day to day. For the purpose of examining the *seasonal* relationship between evaporation and various other meteorological factors (such as relative humidity and wind velocity) mean monthly records obtained at all three stations have also been compared over a period of three years from 1st January, 1931 to 31st December, 1933.

The relationship between different meteorological factors has been determined by severally calculating the correlation coefficients between (a) average daytime relative humidity, (b) minimum relative humidity, (c) maximum saturation deficit, (d) 8 a.m., 2 p.m. and 4 p.m. readings of relative humidity, (e) rate of evaporation, (f) wind velocity and (g) hours of bright sunshine. Values for wind velocity and average relative humidity of the atmosphere have been calculated for the hours of daylight only, since, under Trinidad conditions, these two factors fluctuate very little during the night, the relative humidity being generally at or near saturation point, and the wind velocity almost negligible.

(IV) Comparison of Methods for measuring Atmospheric Humidity.

For standard of comparison, average daytime relative humidity has been taken, as recorded by the hair hygrometer between 8 a.m. and 8 p.m. During this period, the greatest changes in relative humidity of the atmosphere occur in Trinidad, so that this figure most closely represents the humidity conditions of the atmosphere during the day. Correlation coefficients between average daytime humidity and other humidity values obtained by different methods are presented in Table I. The following conclusions are drawn from a consideration of these results.

(a) *Average Relative Humidity and Minimum Relative Humidity.*

These two values are obtained from readings of the same instrument; the high correlation coefficient between them indicates that a very close relationship exists between the *minimum* relative humidity during the day and the *average* relative humidity. Hence it may be assumed that, for all practical purposes, the minimum

daily value may be taken as an accurate measure of the average relative humidity of the atmosphere, so that, in cases where continuous records of humidity are not available, readings of discontinuous hygrometers, obtained at a time of day when relative humidity is lowest, may evidently serve as reliable substitutes.

(b) *Average Relative Humidity and 2 p.m. Relative Humidity.*

Scrutiny of a very large number of charts of the recording hygrometer indicates that the lowest relative humidity value during the day most often occurs in Trinidad at or near 2 p.m. The correlation between 2 p.m. readings and the average daytime humidity, as shown in Table I, indicates a very close relationship between these two values. Hence, under conditions obtaining in Trinidad, spot readings of relative humidity, taken at or near 2 p.m., should give a fairly accurate representation of the moisture status of the atmosphere during the day.

(c) *Average Relative Humidity and Wet and Dry Bulb Thermometer Readings at 8 a.m. and 4 p.m.*

Table I shows that neither of these values can be relied upon to give a true representation of the daily humidity conditions. The 4 p.m. reading shows a closer relationship to the average daily humidity than does the 8 a.m. reading. At these times, the relative humidity is changing very rapidly, and, in addition, the 8 a.m. reading is markedly affected by the period of time that has elapsed between 8 a.m. and sunrise. The time of

sunrise varies in Trinidad by about one hour during the year, and therefore, irrespective of weather conditions, the relative humidity of the atmosphere at 8 a.m. will be higher during the shorter days.

(d) *Average Relative Humidity and Maximum Wet Bulb Thermometer Readings.*

The minimum relative humidity of the air during the day usually occurs at the time of maximum shade temperature. Hence, readings obtained from a maximum wet bulb thermometer might give a closer approximation to humidity conditions during the day than spot readings taken twice daily at 8 a.m. and 4 p.m. The maximum wet bulb thermometer possesses the advantage that it need only be read once a day during the evening. In Table I, it is shown that the relative humidity values calculated from the maximum wet and dry bulb readings are indeed more closely related to the average daily humidity than spot readings taken either at 8 a.m. or at 4 p.m. Values obtained from the maximum wet bulb readings, however, do not give such a close representation of average daily humidity as the minimum values and the 2 p.m. readings of the hair hygrometer, because the maximum wet bulb temperature does not necessarily occur at the same time as the maximum dry bulb temperature, which is the time of minimum humidity. Furthermore, the reading of a wet bulb thermometer is not affected by relative humidity of the air only; it is also markedly affected by air movement, which varies independently of relative humidity.

Table I.

Correlation between Average Daily Relative Humidity of the Atmosphere and Relative Humidity recorded by Different Methods and Instruments.

DAILY RECORDS.

Factors Correlated.	Method of Measurement.	No. of Measurements, <i>n</i> .	Value of <i>r</i> , Correlation Coefficient.	Value of <i>Z</i> = <i>r</i> .
Average rel. humidity ..	.. Hair Hygrometer ..	35	+.971	2.110
Minimum rel. humidity ..	.. Hair Hygrometer			
Average rel. humidity ..	.. Hair Hygrometer	35	+.680	0.830
4 p.m. rel. humidity ..	.. Wet and Dry Thermometer ..			
Average rel. humidity ..	.. Hair Hygrometer	35	+.482	0.528
8 a.m. rel. humidity ..	.. Wet and Dry Thermometer ..			
Average rel. humidity ..	.. Hair Hygrometer ..	35	+.761	1.008
Minimum rel. humidity ..	.. Max. Wet Thermometer			
Average rel. humidity ..	.. Hair Hygrometer	35	+.900	1.472
2 p.m. rel. humidity ..	.. Hair Hygrometer			
Average rel. humidity ..	.. Hair Hygrometer	35	-.895	1.448
Evaporation	.. White Bulb Atmometer			
Average rel. humidity ..	.. Hair Hygrometer	35	-.888	1.412
Evaporation	.. Black Bulb Atmometer			

In order that differences between correlation coefficients (*r*) may be statistically significant, differences between corresponding values of *Z* must exceed 0.5.

(c) *Average Relative Humidity and Rate of Evaporation.*

The data in Table I show that there is a very close relationship between the daily rate of evaporation and the average daily relative humidity. Furthermore, in Table V, and in Figs. 1, 2 and 3, relative humidity and rate of evaporation have been compared for three distinct environments, and it is shown that, in each environment, there is a very close relationship between relative humidity of the air and rate of evaporation. Between *different* environments, however, relative humidity and evaporation records are not comparable. Hence it may be concluded that records obtained from an evaporimeter of the type of the Livingston atmometer give an accurate representation of fluctuations in atmospheric humidity within a specified particular environment.

(V) *Relationship between Evaporation and Various Meteorological Factors.*

The rate of evaporation of water is influenced by a number of factors, including temperature, relative humidity, rate of movement of the air, and solar radiation. These different factors are closely interdependent. For example, air temperature varies with solar radiation, and relative humidity varies inversely with temperature, since, as the temperature rises, the air becomes capable of holding larger amounts of water-vapour, so that, even though absolute humidity remains the same, relative humidity decreases. Furthermore, a fairly close relationship exists between the amount of wind and the amount of cloud, and therefore the amount of sunshine. On still days, ascending masses of moist warm air form clouds of the heavy cumulus and cumulo-nimbus type, which obscure the sun for long periods, particularly during the

Table II.

Total Correlation between Evaporation (as shown by Black and White Bulb Livingston Atmometers) and Various other Meteorological Factors.

DAILY RECORDS.

Factors Correlated.		Method of Measurement.		No. of Measurements, <i>n</i> .	Correlation Coefficient, <i>r</i> .	Value of $Z=r$.
Evaporation		White Bulb Atmometer				
Average rel. humidity	..	Hair Hygrometer	..	35	-.895	1.448
Evaporation	..	White Bulb Atmometer				
Minimum rel. humidity	..	Hair Hygrometer	..	35	-.935	1.698
Evaporation	..	White Bulb Atmometer	..			
Relative humidity	..	Wet and Dry Thermometers	..	35	-.789	1.068
Evaporation	..	White Bulb Atmometer				
Wind velocity	..	Cup Anemometer	..	35	+.690	0.848
Evaporation	..	White Bulb Atmometer				
Hours of sunshine	..	Campbell-Stokes Recorder	..	35	+.819	1.151
Evaporation	..	White Bulb Atmometer				
Saturation deficit	..	Max. Temp. Min. Rel. Humidity	..	35	+.927	1.638
Evaporation	..	Black Bulb Atmometer				
Average rel. humidity	..	Hair Hygrometer	..	35	-.888	1.412
Evaporation	..	Black Bulb Atmometer				
Minimum rel. humidity	..	Hair Hygrometer	..	35	-.897	1.458
Evaporation	..	Black Bulb Atmometer				
Relative humidity	..	Wet and Dry Thermometers	..	35	-.773	1.028
Evaporation	..	Black Bulb Atmometer				
Wind velocity	..	Cup Anemometer	..	35	+.698	0.864
Evaporation	..	Black Bulb Atmometer				
Hours of sunshine	..	Campbell-Stokes Recorder	..	35	+.885	1.398
Evaporation	..	Black Bulb Atmometer				
Saturation deficit	..	Max. Temp. Min. Rel. Humidity	..	35	+.901	1.478
Radiation	..	Diff. Black-White				
Hours of sunshine	..	Campbell-Stokes Recorder	..	35	+.794	1.082

middle of the day and early afternoon. On windy days, however, the sky is comparatively free from cloud, and such clouds as occur are of the fracto-cumulus type, which seldom obscure the sun for more than a few minutes at a time. All these different meteorological factors therefore are closely related one to another, and all exert a marked effect on the evaporation of water. In this investigation, total correlation coefficients have been calculated between evaporation rate and each individual factor in turn, so as to obtain a measure of the value of the different meteorological instruments and of the different methods of observation employed for determining atmospheric evaporating ability. Readings of the black and the white bulb atmometers have been considered separately.

In view of the interdependence of the various factors examined, it has been necessary to calculate also a number of partial correlation coefficients in order to obtain a comparative measure of the degree to which each factor separately influences the rate of evaporation. By this means it has been possible to show the effect on evaporation of *each factor separately*, whilst eliminating the effects of other factors. The correlations are shown in Tables II and III.

From the results presented in Tables II and III, the following conclusions may be drawn:—

(a) *Evaporation and Minimum Relative Humidity*.—There is a very close relationship between the minimum relative humidity recorded during the day and the daily rate of evaporation. In fact, the relationship between these two values appears to be closer than the relationship between *average* relative humidity and rate of evaporation. In section IV (a) of this paper, it was shown that the minimum humidity recorded during the day gave a very precise indication of the average humidity throughout the day, and it was concluded that the minimum relative humidity could be considered just as accurate a representation of daily humidity as the calculated average humidity. The results now obtained furnish evidence that the minimum relative humidity may provide a better measure of the moisture status of the atmosphere during the day, since the minimum value appears to be the more closely related to evaporating ability. Comparing the values of the white bulb and the black bulb, it will be seen that the white bulb readings show a distinctly closer relationship to relative humidity than the black bulb readings. This fact is particularly clearly demonstrated by the partial correlation

Table III.

Partial Correlation between Evaporation (as shown by Black and White Bulb Livingston Atmometers) and Daily Fluctuations in other Meteorological Factors.

Factors Correlated.	Factors Eliminated.	No. of Measurements, <i>n</i> .	Correlation Coefficient, <i>r</i> .	Value of $Z=r$.
Evaporation, white bulb Minimum rel. humidity	.. Wind velocity	35	-.968	2.060
Evaporation, white bulb Wind velocity	.. Relative humidity	35	+.860	1.292
Evaporation, white bulb Hours of sunshine	.. Relative humidity	35	+.480	0.524
Evaporation, white bulb Hours of sunshine	.. Wind velocity and relative humidity	35	+.091	0.091
Evaporation, black bulb Minimum rel. humidity	.. Wind velocity	35	-.914	1.551
Evaporation, black bulb Wind velocity	.. Relative humidity	35	+.753	0.980
Evaporation, black bulb Hours of sunshine	.. Relative humidity	35	+.713	0.893
Evaporation, black bulb Hours of sunshine	Wind velocity and relative humidity	35	+.579	0.661
Evaporation, black bulb Wind velocity	Relative humidity and hours of sunshine	35	+.644	0.765
Radiation Hours of sunshine	.. Wind velocity and relative humidity	35	+.737	0.944

between evaporation and minimum humidity when the effect of wind velocity is eliminated. From these results, the conclusion may be drawn that, for a given environment, records of minimum relative humidity form an accurate index of the evaporating ability of the air at that particular site (Table II).

The partial correlation coefficients presented in Table III indicate that the relative humidity of the air is the chief factor limiting the rate of evaporation.

(b) *Evaporation and Maximum Saturation Deficit.*—The saturation deficit of the atmosphere is the amount by which the pressure of aqueous vapour present in the atmosphere falls below its saturation pressure. The value of the saturation deficit is influenced to a marked degree by temperature, as well as by the relative humidity of the atmosphere. For instance, the value of the saturation deficit at a temperature of 80°F. and 50 per cent. relative humidity is 17.5 milibars, but the saturation deficit at a temperature of 86°F. and 50 per cent. relative humidity is 21.2 milibars. Thus, although the relative humidity of the atmosphere is the same in the two cases, at the higher temperature, the aqueous vapour in the air is further away from its saturation point, and therefore the evaporating ability of the air is the greater. Where wide fluctuations in temperature are encountered, and when seasonal comparisons are being made between contrasted environments exhibiting widely different air temperatures, the saturation deficit will obviously give a better measure of the evaporating ability of the air than the relative humidity. Many ecologists and meteorologists have therefore recommended its use instead of the relative humidity value as a measure of the moisture status of the atmosphere. Thus, Prescott (4) in Australia has concluded that the evaporation from a free water surface is a linear function of the saturation deficit. In the present investigation, the maximum saturation deficit for each day has been calculated from the minimum relative humidity and the maximum temperature. The minimum daily humidity usually occurs at the time of maximum temperature, but not invariably, and therefore the calculated values for the maximum saturation deficit are not absolutely accurate. This fact must be duly considered when interpreting the results presented in Table II. These results indicate that there is indeed a very close relationship between the rate of evaporation and the saturation deficit, but the relationship is approximately of the same order as that between rate of evaporation and minimum relative humidity. It can be concluded, therefore, that, under conditions obtaining in Trinidad, no great advantage is obtained by using the saturation deficit instead of the relative humidity as a measure of the moisture status of the atmosphere. Apparently the daily fluctuations in shade temperature are so small in Trinidad that they exert little effect on the comparative values of the saturation deficit and the relative humidity of the atmosphere.

(c) *Evaporation and Hours of Sunshine.*—The data in Table II show that a close relationship apparently exists between the daily rate of evaporation and the total number of hours of bright sunshine. In attempting to interpret this result, however, the indirect effects of sunshine on evaporation must be considered, for, besides the direct effect of radiation in increasing evaporation, the indirect effects of sunshine, through its influence on air temperature, and therefore on the relative humidity of the air, are also important. These facts are clearly illustrated by the partial correlations presented in Table III. Considering first the data for the white bulb atmometer, it is seen that, when the effect of relative humidity is eliminated, a much smaller degree of correlation between sunshine and evaporation is obtained, and when the combined effects of wind and relative humidity are both eliminated, no significant relationship between sunshine and evaporation is revealed. On the other hand, the data for the black bulb atmometer show a much closer relationship to hours of sunshine than the white bulb readings. Even when the combined effects of wind and relative humidity are eliminated, a significant positive relationship is demonstrated between evaporation and sunshine, doubtless due to the direct effects on the black atmometer of solar factors such as diffuse radiant heat.

(d) *Evaporation and Maximum Wet Bulb Thermometer Records.*—A fairly close relationship between evaporation and relative humidity is shown by the differences between the maximum wet and dry bulb thermometer readings. This method of measuring relative humidity is preferable to spot readings taken at 8 a.m. and 4 p.m., but it does not give nearly as accurate a representation of the moisture status of the atmosphere as the values obtained from the recording hygrometer. The records obtained from the wet and dry bulb hygrometer appear to be more closely related to rate of evaporation than to relative humidity of the air.

(e) *Evaporation and Wind Velocity.*—The total correlation coefficients presented in Table II show only a slight relationship between average daily rate of evaporation and average daily wind velocity. This is due to the fact that wind velocity and relative humidity may sometimes affect the evaporating ability of the air in opposite directions, and on such occasions the effect of high wind velocity in increasing the rate of evaporation may be masked by the opposing effect of high relative humidity. For instance, rainstorms in Trinidad are usually accompanied by winds of high velocity (20 miles per hour or more) which contribute to a high average daily wind velocity, but do not necessarily affect the rate of evaporation, because the moving air is saturated by water vapour. Hence it may be concluded that records of average daily wind velocity do not provide a reliable index of rate of evaporation.

When the effect of relative humidity is eliminated from the factors deciding the rate of evaporation, by calculating the partial correlation

coefficient, a much closer relationship between rate of evaporation and wind velocity is demonstrated (Table III). These results clearly show that wind velocity has a marked effect on the evaporating ability of the air. The rate of evaporation as measured by the white bulb atmometer shows a closer relationship to wind velocity than the rate of evaporation as measured by the black bulb atmometer.

(f) *Radiation and Hours of Sunshine.*—Due to the differential effects of solar radiation on the rate of evaporation of the black and white bulb atmometers, the difference between the readings of the two types of atmometer gives a value for the amount of evaporation due to radiation only, and should therefore provide a measure of the amount of solar radiation. The data in Tables II and III show that there is only a fair degree of relationship between daily values for radiation obtained by the above method and hours of bright sunshine. The rate of evaporation from the black bulb atmometer may be susceptible to other radiation effects besides those of bright sunshine only, and it must be concluded therefore that these records of solar radiation are of doubtful value, since they cannot readily be correlated with any other easily measurable environmental factors.

(VI) Relationship between Evaporation and Meteorological Factors: Seasonal Fluctuations.

For the purpose of further comparisons, the mean monthly values for evaporation have been compared with the mean monthly values for

various other meteorological factors over a period of three years (January, 1931 to December, 1933), and an additional set of correlation coefficients have been thus calculated for seasonal fluctuations. The results are given in Table IV.

The results obtained for *seasonal* fluctuations generally confirm the findings demonstrated in previous sections for *daily* fluctuations. The biggest difference between the two sets of results is revealed by the closer relationship that is demonstrated for periodic seasonal changes in wind velocity as a factor deciding rate of evaporation. This finding is merely an expression of the fact that, during the dry season of relatively low humidity, the belt of equatorial calms lies to the south of Trinidad, and the northeast trade winds are strongest, whilst during the wet humid season, Trinidad is within the belt of equatorial calms, and the trade winds have subsided. Hence, the two factors, wind velocity and relative humidity of the atmosphere, naturally both tend to cause an increase in the rate of evaporation at the same time, and it is more difficult to obtain a comparative measure of the individual effect which each of these two factors separately exerts on the rate of evaporation. The seasonal fluctuations in duration of bright sunshine are also demonstrated to be closely related to rate of evaporation, which further indicates that, in Trinidad, the various meteorological factors affecting evaporation show similar seasonal fluctuations.

Table IV.

Total Correlation between Evaporation (as shown by Livingston Black and White Atmometer Bulbs) and Seasonal Fluctuations in other Meteorological Factors (Mean Monthly Values from Jan., 1931 to Dec., 1933).

Factors Correlated.	Methods of Measurement.	No. of measurements, <i>n</i> .	Correlation Coefficient, <i>r</i> .	Value of $Z=r$.
Evaporation Minimum rel. humidity	White Bulb Atmometer	36	-.918	1.578
Evaporation Wind velocity	White Bulb Atmometer	36	+.911	1.534
Evaporation Saturation deficit	White Bulb Atmometer	36	+.882	1.384
Evaporation Hours of sunshine	White Bulb Atmometer	36	+.855	1.274
Evaporation Minimum rel. humidity	Black Bulb Atmometer	36	-.931	1.666
Evaporation Wind velocity	Black Bulb Atmometer	36	+.884	1.393
Evaporation Saturation deficit	Black Bulb Atmometer	36	+.880	1.374
Evaporation Hours of sunshine	Black Bulb Atmometer	36	+.905	1.409

(VII) Comparative Values of Relative Humidity and Rate of Evaporation in Different Environments.

In Table V, records of atmospheric humidity and rate of evaporation have been compared for three *different* environments in order to determine the relative value of these records as a means of measuring atmospheric humidity conditions in different environments. The particular records that have been considered are mean monthly values taken over a period of 24 months, from March, 1931 to February, 1933. The environments investigated were (a) an exposed pasture (Imperial College Meteorological Station), (b) a "good" cacao environment (Torrecilla Estate, Arima), and (c) a "bad" cacao environment (Las Hermanas Estate, San Rafael). The data set out in Table V are graphically presented in Figs. 1 to 5.

Figs. 1, 2 and 3 show that, when each environment is considered separately, there is a very close relationship between relative humidity of the air and rate of evaporation. This relationship is so close that, in each environment, the relative humidity may be taken as a fairly accurate index

of the rate of evaporation, and *vice versa*. By means of the regression coefficient between these two factors, it is possible to calculate the rate of evaporation for any particular period with a fair degree of accuracy from the observed value of the relative humidity for that period. The calculated regression coefficients shown in Figs. 1, 2 and 3 demonstrate that, at the exposed site, there is a much greater variation in rate of evaporation with each unit variation in relative humidity than at either of the cacao plots. The value of the regression coefficient for the exposed environment is more than three times as great as the values of the regression coefficients at the two sheltered cacao plots. In different types of environments therefore, records for relative humidity and for rate of evaporation will not be comparable. This is clearly shown in Figs. 4 and 5, and by the average values recorded at the foot of Table V. During dry periods, the records of relative humidity actually indicate drier atmospheric conditions within the sheltered environment of one of the cacao plots than at the exposed site of the College Meteorological Station. Records obtained with

Table V.

Comparison between Relative Humidity of the Atmosphere and Rate of Evaporation in Different Environments (Mean Monthly Values from Mar., 1931 to Feb., 1933).

Date.	Relative Humidity (Minimum).			Evaporation (cc. per 24 hours).		
	Open Pasture.	"Good" Cacao Field.	"Bad" Cacao Field.	Open Pasture.	"Good" Cacao Field.	"Bad" Cacao Field.
1931.						
March	45.3	53.3	43.0	48.8	16.3	17.7
April	47.5	55.1	45.4	49.4	15.7	17.2
May	45.9	54.9	44.0	52.2	14.3	21.8
June	58.4	69.5	57.8	32.7	8.9	13.2
July	60.1	70.0	65.0	24.9	4.7	6.2
August	61.1	70.1	69.3	23.2	6.0	5.8
September	59.7	65.9	61.5	21.0	7.4	7.1
October	62.4	72.1	70.0	17.8	4.6	4.3
November	64.4	78.1	74.8	15.8	3.7	4.5
December	60.3	73.5	76.2	15.4	2.2	2.5
1932.						
January	58.8	68.4	66.0	19.2	7.3	5.7
February	53.6	55.2	50.9	27.0	11.9	11.2
March	55.8	59.0	55.0	28.2	11.2	9.5
April	57.2	64.4	60.1	33.5	8.6	7.8
May	61.3	68.3	65.0	26.4	6.5	7.2
June	65.4	71.2	73.4	19.4	6.9	4.5
July	61.3	64.5	66.1	25.1	7.4	5.7
August	62.8	69.4	69.5	17.7	5.3	3.7
September	58.7	66.7	68.4	19.4	7.0	5.1
October	59.8	67.0	66.2	20.4	7.8	5.4
November	59.8	65.3	63.5	20.2	8.9	6.1
December	62.0	69.7	73.1	17.2	6.3	3.6
1933.						
January	59.2	65.5	63.8	23.2	9.9	5.5
February	53.0	55.7	52.9	30.6	14.9	8.5
Average: 7 Dry months	51.2	56.8	50.2	38.5	13.3	13.4
Average: 17 Wet months	60.9	69.2	67.7	21.1	7.4	5.6
Average: Whole period	58.1	65.5	62.5	26.2	8.5	7.9

atmometers, however, show that the rate of evaporation at the exposed site is approximately *three times as great* as the rate of evaporation at the cacao plots. This conclusively demonstrates that relative humidity records may be of little value for comparing the atmospheric moisture status of *different* types of environment, whereas, within the *same* environment, records of relative humidity do indeed give an accurate representation of daily and seasonal fluctuations in atmospheric moisture conditions. Evidently, therefore, measurements of the evaporating ability of the air by means of instruments such as the Livingston atmometer are necessary in comparative studies of widely different environments.

(VIII) General Conclusions.

Methods for measuring the humidity of the atmosphere may be divided into two classes, (a) methods which give an accurate representation of climatic and seasonal fluctuations in a *particular* environment, and (b) methods which serve to compare the conditions existing in *different* environments. The most satisfactory instrument for measuring climatic and seasonal fluctuations is the recording hair hygrometer, which yields continuous records of the relative humidity of the air. From such records, the daily minimum value gives an accurate representation of the humidity of the air throughout the day, and also provides a reliable index of the evaporating ability of the air within a particular environment. Under conditions obtaining in Trinidad, daily fluctuations in shade temperature are so slight that there is apparently no advantage in employing the saturation deficit of the air instead of the relative humidity as an index of the rate of evaporation. When different environments or seasons with widely different air temperatures are being compared, the saturation deficit of the atmosphere doubtless gives a much more accurate index of the evaporating ability of the air than the relative humidity, and, in such cases, records of temperature as well as relative humidity of the air will be necessary. Under conditions in Trinidad, records of minimum relative humidity, obtained from a recording hair hygrometer of reliable type (such as Negretti and Zambra's model M. 2249, price £9), form the most convenient and most accurate method for measuring daily and seasonal fluctuations in atmospheric humidity in ecological studies. In Trinidad (and probably in a great many other humid tropical countries), a very useful check on the accuracy of these instruments is provided by the fact that nearly every night the atmosphere becomes saturated with water vapour and dew is deposited. The possible value of data obtained from recording wet and dry bulb hygrometers has not been discussed, since the cost of reliable types of these instruments is prohibitive for ecological work.

If it is impossible to obtain a recording hygrometer owing to reasons of expense, daily readings of various types of hygrometers should be carried out as close as possible to the time of minimum

humidity. In Trinidad, the minimum relative humidity of the atmosphere generally occurs at or near 2 o'clock in the afternoon, and 2 p.m. readings of relative humidity have been shown to bear a very close relationship to the average daily humidity. Daily readings of relative humidity, taken in the morning or during the late afternoon, give only a slight indication of humidity conditions existing throughout the day. With regard to the type of hygrometer suitable for taking measurements of atmospheric humidity, the whirling hygrometer is recommended in preference to the stationary type of wet and dry bulb thermometer, since, in the whirling hygrometer, variations in the reading of the wet bulb thermometer, due to air movement, are eliminated. Recently, several ingenious types of direct reading hygrometers have been devised. Prominent among these is the paper hygrometer, obtainable from Messrs. A. Gallenkamp & Co., London. These instruments depend for their action on the expansion and contraction of a strip of specially-treated paper, caused by changes of humidity. The smaller instruments cost about ten shillings; they are the same size as an ordinary pocket watch, and are of robust construction, so that they can be carried in the pocket without fear of damage. One of these instruments has recently been tested at the Meteorological Station of the Imperial College of Tropical Agriculture in comparison with a Negretti and Zambra hair hygrometer, and a very close agreement between the readings of the two instruments has been obtained. The paper hygrometer, however, shows a greater lag than the hair hygrometer, that is, it does not respond so quickly to changes of humidity. Although the paper hygrometer is not, perhaps, a scientifically precise instrument, daily readings taken with some such simple instrument at or near the time of minimum humidity (about 2 p.m. in Trinidad) quite accurately represent the humidity of the atmosphere during the day. Such measurements undoubtedly give a more accurate indication of average daily humidity than daily readings of the standard wet and dry bulb thermometers which are usually taken at 8 a.m. and 4 p.m., or at 9 a.m. and 3 p.m. The paper hygrometer seems to be especially suitable for use in outlying stations. It can be used by untrained observers with every likelihood of accurate records being obtained.

Methods of measuring Atmospheric Humidity which serve to compare the Conditions existing in Different Environments.

Records of relative humidity of the air may sometimes be very misleading as a measure of the atmospheric humidity existing in widely different environments, especially in cases where exact data regarding the evaporating ability of the air are required. Micro-climatic differences are much more pronounced and much more common with respects to evaporation than with respects to many other commonly-measured factors, such, as temperature, rainfall and relative humidity of the air. Thus relative humidity records obtained

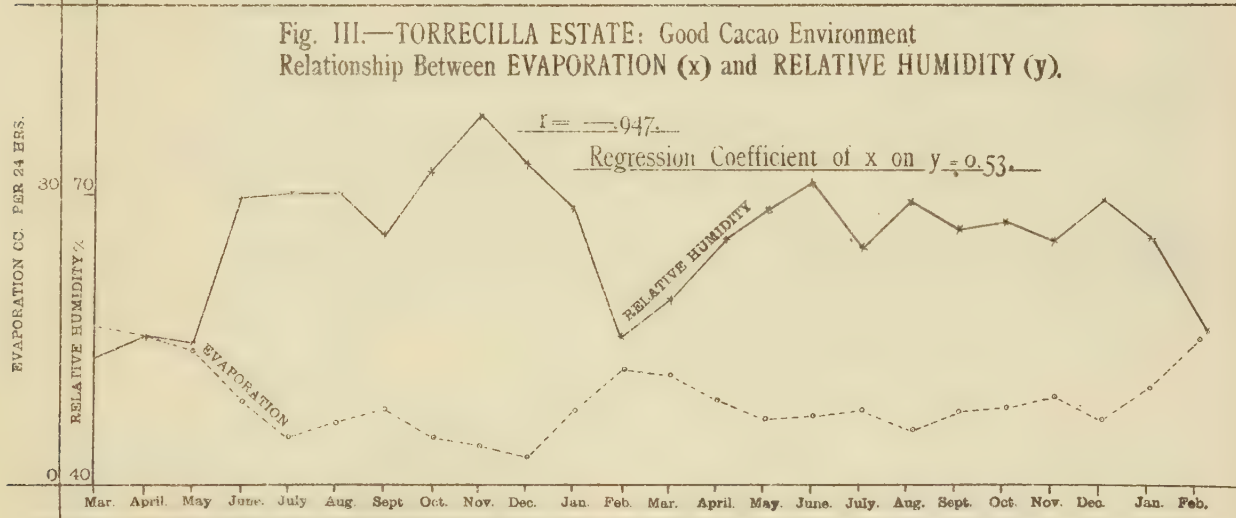
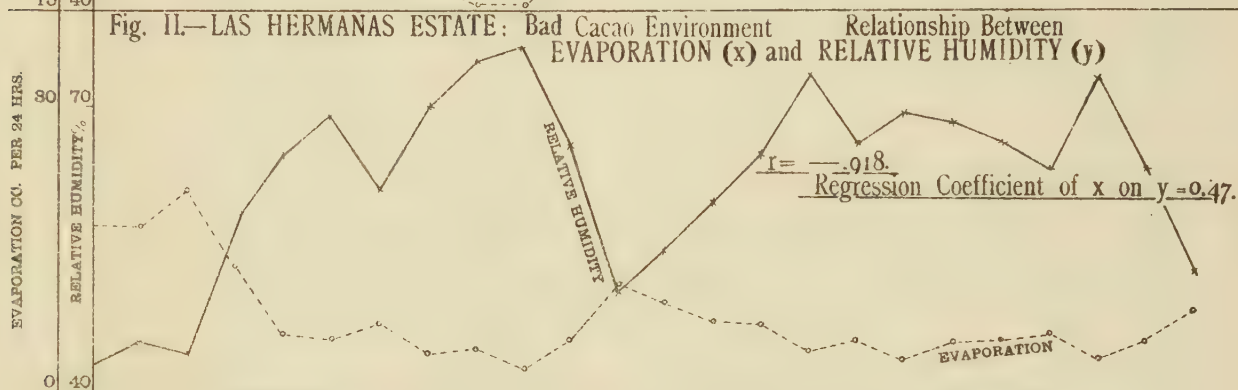
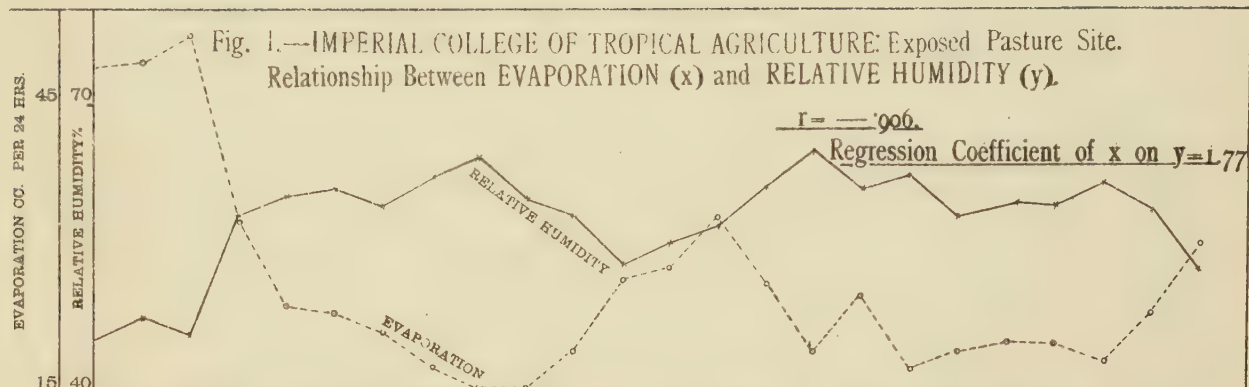


Fig IV.—RELATIVE HUMIDITY OF THE AIR IN DIFFERENT ENVIRONMENTS

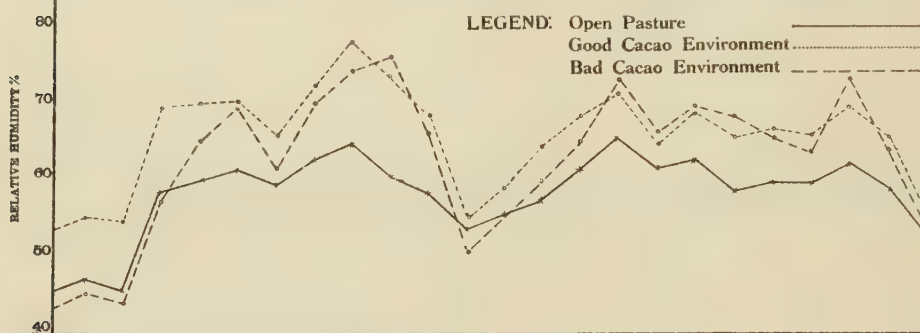
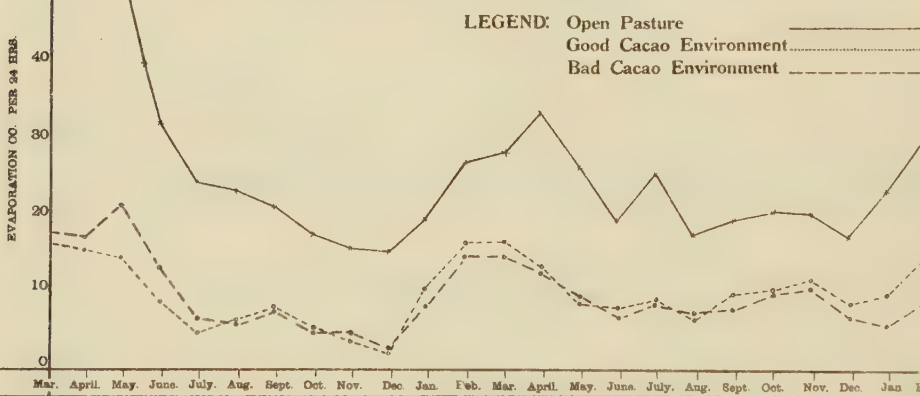


Fig V—EVAPORATING ABILITY OF THE AIR IN DIFFERENT ENVIRONMENTS



from an open pasture and from typical cacao fields show apparently little difference in atmospheric humidity conditions between the two environments. Measurements of evaporation by means of Livingston atmometers, on the other hand, show that the rate of evaporation in the open environment is approximately three times the rate of evaporation in the sheltered environment of the cacao fields. An instrument for measuring the evaporating ability of the air is essential, therefore, in any ecological investigation which aims at comparing the atmospheric moisture status at *different sites* or environments. It is claimed that Livingston atmometers are far more sensitive to small differences in low wind velocities than any other climatological instrument, except perhaps the wet bulb thermometer, with which it is difficult to obtain a satisfactory integration over a period of fluctuating air movements. The great differences in rate of evaporation demonstrable in different environments are almost certainly due to differences in wind velocity, since relative humidity of the air may differ but little between two contrasted environments. A critical examination of the various factors influencing evaporating ability has shown that the relative humidity of the atmosphere, or more strictly its saturation deficit, is the chief factor limiting the rate of evaporation, but that the general level or total amount of evaporation is greatly influenced by the degree of exposure to wind of the particular environment. The accurate measurement of rate of evaporation is obviously to be preferred to the measurement of relative humidity in ecological investigations of the effects of environmental moisture conditions on the growth of the plant, since the factors influencing transpiration are similar to those influencing the evaporation of water from an exposed surface. On the other hand, records of relative humidity provide a measure of *one factor* only that influences evaporation and transpiration. Records of relative humidity may be of greater usefulness than records of rate of evaporation, however, in investigations of environmental conditions in relation to the incidence of insect pests and fungal diseases.

(IX) Summary.

(1) A number of different methods for measuring the relative humidity and the evaporating ability of the air have been examined, with a view to ascertaining the most suitable methods for assessing the atmospheric moisture status of a particular environment in ecological studies. The most suitable methods will depend on the particular type of problem that is being investigated.

(2) Continuous records of relative humidity give an accurate indication of daily and seasonal fluctuations in atmospheric humidity and in rate of evaporation.

(3) The minimum daily value of relative humidity accurately represents the average daily humidity, and therefore, where continuous records are not available, daily readings of relative humidity should be taken at or near the time of minimum humidity, which generally coincides with the time of maximum shade temperature.

(4) Under conditions obtaining in Trinidad daily readings of relative humidity taken at 2 p.m. show a very close relationship to average daily humidity. Daily readings taken at 8 a.m. and 4 p.m. show only a small relationship to average daily humidity.

(5) The daily rate of evaporation appears to be more closely related to the minimum than to the average daily relative humidity.

(6) The relative humidity of the air (or more strictly its saturation deficit), is the chief factor limiting the rate of evaporation.

(7) Under conditions in Trinidad, there is no advantage in employing the saturation deficit of the air instead of relative humidity as a measure of the rate of evaporation, because daily and seasonal fluctuations in shade temperature here are very small.

(8) Rate of evaporation is also closely related to wind velocity, and, although in any particular environment, fluctuations in the rate of evaporation closely follow the fluctuations in relative humidity, *the general level of evaporation and the magnitude of the fluctuations depend on the degree of exposure of the site.*

(9) Measurements of evaporating ability of the air are therefore essential in investigations which attempt to compare the atmospheric moisture status of widely *different* environments.

(10) Records of rate of evaporation, obtained by means of Livingston atmometers, have proved of great value in ecological investigations in Trinidad. By this means it has been possible to demonstrate great differences in the atmospheric moisture status of contrasted environments which were not revealed by records of relative humidity. Livingston atmometers also provide valuable information regarding atmospheric moisture conditions at different levels or strata in the same environment, since they are very sensitive to small fluctuations in low wind velocity.

(X) References.

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